

McMahon & Mann

Consulting Engineers, P.C.

APPENDICES I-IX

PHASE I:

**CONDITION ASSESSMENT AND EVALUATION OF ROCK
REINFORCEMENT**

ALONG I-93

BARRON MOUNTAIN ROCK CUT

WOODSTOCK, NEW HAMPSHIRE

Prepared for:

**The New Hampshire Department of Transportation
Bureau of Materials and Research
Concord, New Hampshire**

Prepared by:

**McMahon & Mann Consulting Engineers, P.C.
2495 Main Street
Buffalo, New York**

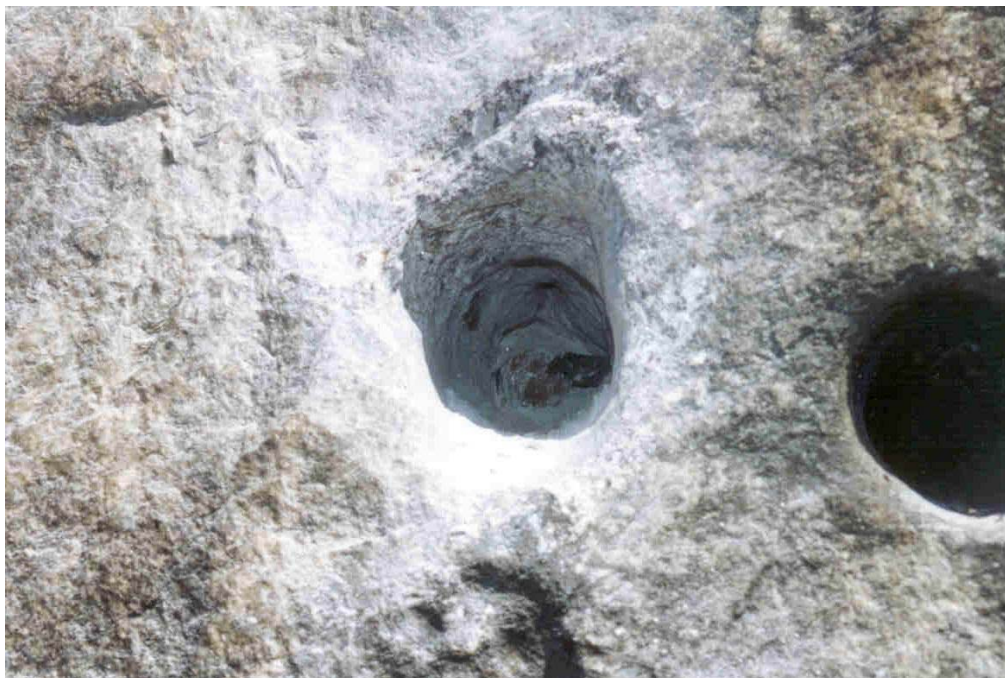
**February 2004
File: 03-024**

APPENDICES

- I Exposed Ends Of Rock Tendons
- II Half-Cell Locations
- III Lab Test Results From NHDOT
- IV Detailed Calculations For Service-Life Estimates
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- VIII Rock Tendons: Impact Acceleration Time Histories
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- X Cost Proposal For Phase II (Included under separate cover with report)

APPENDIX I

EXPOSED ENDS OF ROCK TENDONS



Photograph 1 – Exposed end of Tendon 1-1 after chipping



Photograph 2 – Exposed end of Tendon 2-1 after chipping



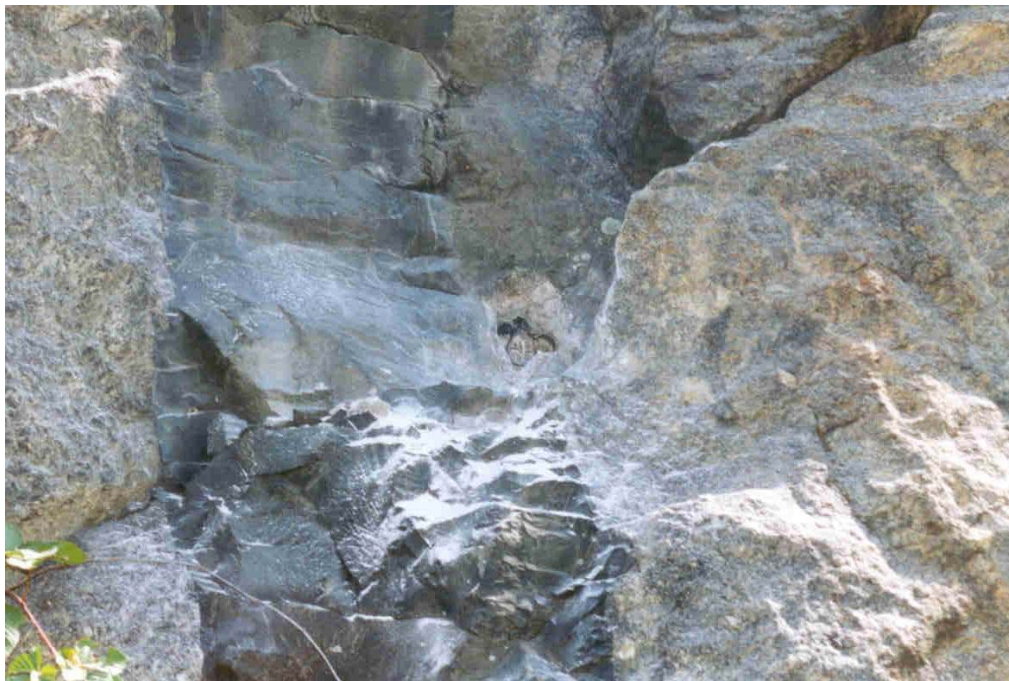
Photograph 3 – Exposed end of Tendon 2-2 after chipping



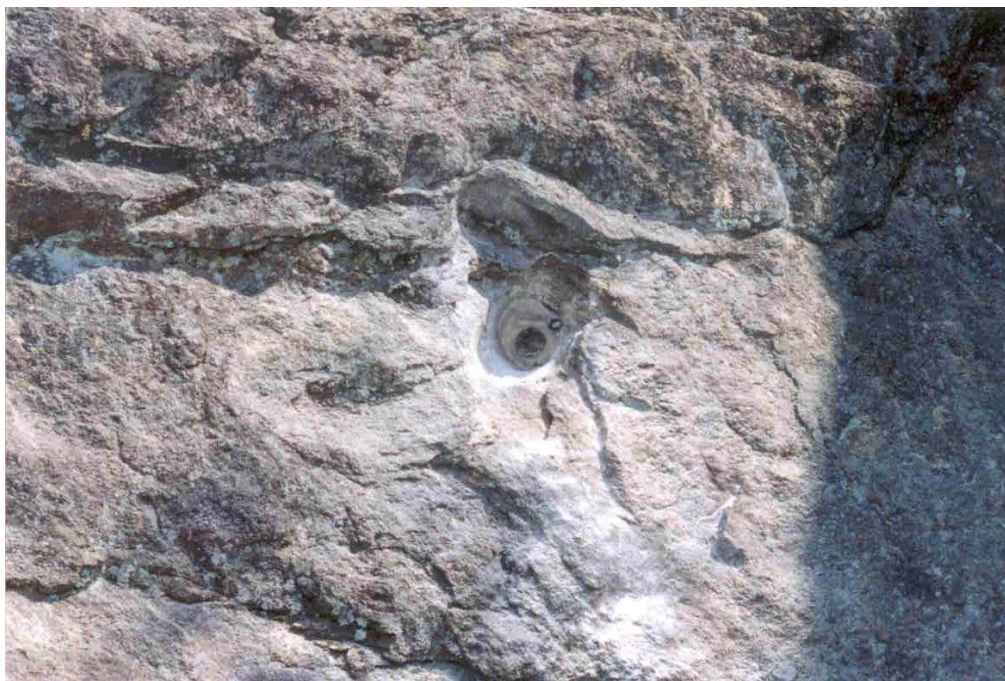
Photograph 4 – Exposed end of Tendon 3-1 after chipping



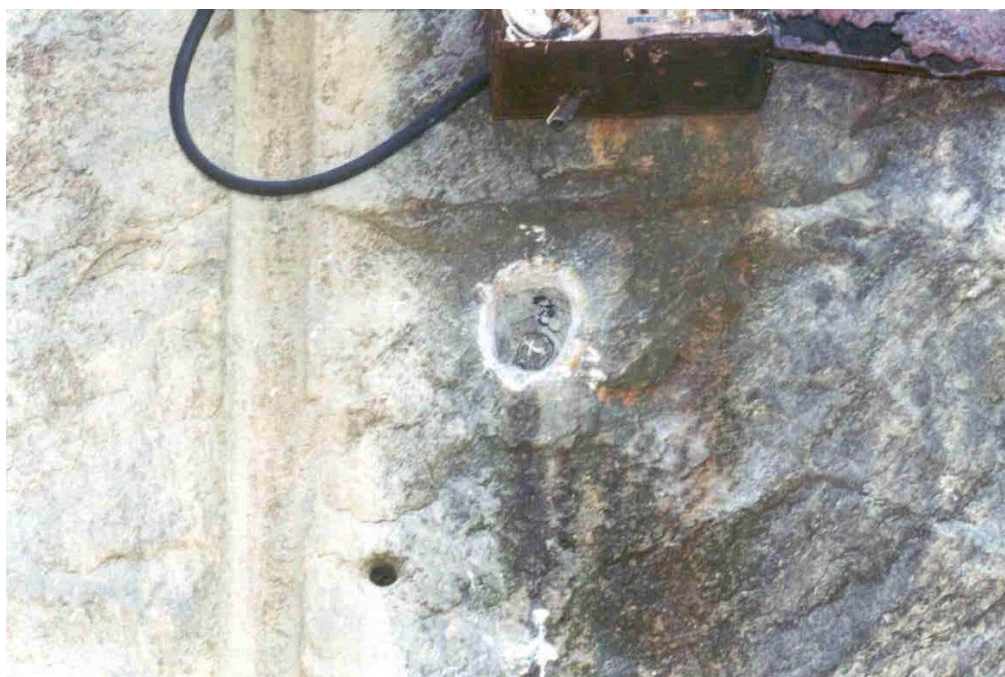
Photograph 5 – Exposed end of Tendon 3-2 after chipping



Photograph 6 – Exposed end of Tendon 4-1 after chipping



Photograph 7 – Exposed end of Tendon 4-2 after chipping



Photograph 8 – Exposed end of Tendon 5-1 after chipping



Photograph 9 – Exposed end of Tendon 5-2 after chipping

APPENDIX II

HALF-CELL LOCATIONS

Table II-1. Half-Cell Locations

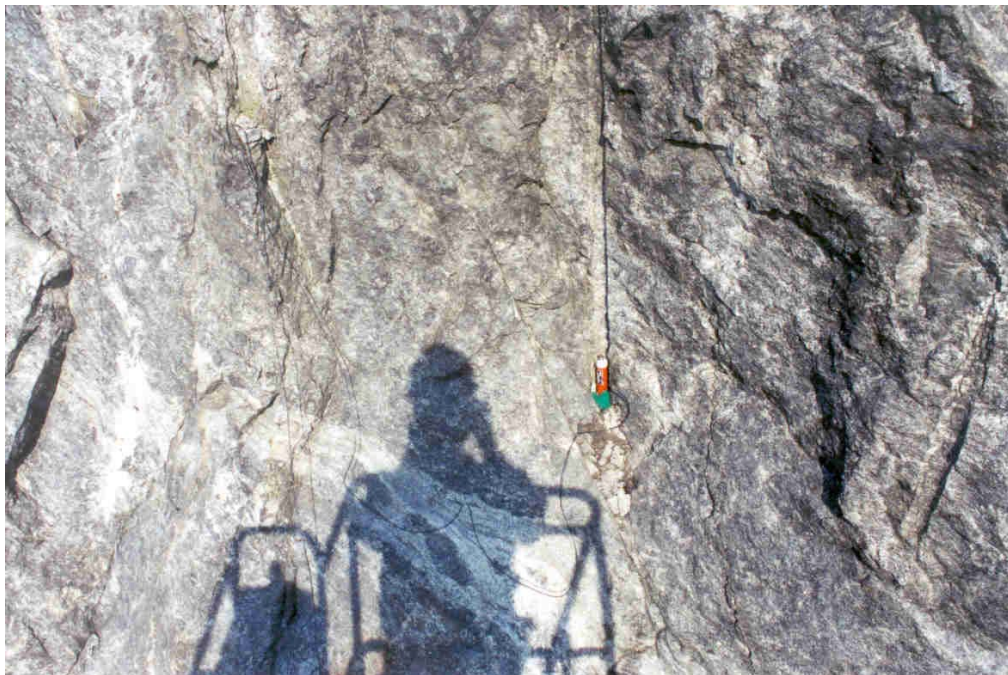
Tendon #	Half-Cell Location
1-1	Drill-hole adjacent to Tendon 1-1
1-2	Drill-hole adjacent to Tendon 1-1
1-3	Drill-hole approx. 6" North of Tendon 1-4 ; see Appendix II, Photo #1
1-4	Drill-hole approx. 6" North of Tendon 1-4; see Appendix II, Photo #1
2-1	Drill hole approx. 18" South and above Tendon 2-1
2-2	Drill hole approx. 18" South and above Tendon 2-1
2-3	Approx. 10 ft. North of Tendon 2-3
2-4	Vertical drill-hole approximately 3 ft. above Tendon 2-4; see Appendix II, Photo #2
3-1	Rock joint approx. 4 ft. North and above Tendon 3-2; see Appendix II, Photo #3
3-2	Rock joint approx. 4 ft. North and above Tendon 3-2
3-3	Rock joint between and to the North of Tendons 3-3 and 3-4
3-4	Rock joint between and to the North of Tendons 3-3 and 3-4
4-1	Rock joint approx. 3 ft. S. of Tendon 4-1 and 5 ft. N. of Tendon 4-2; see Appendix II, Photo #4
4-2	Rock joint approx. 3 ft. S. of Tendon 4-1 and 5 ft. N. of Tendon 4-2
4-3	Rock joint approx. 5 ft. South of Tendon 4-3
4-4	Rock joint approx. 5 ft. South of Tendon 4-3
5-1	Drain hole approx. 5 ft. South of Tendon 5-3; see Appendix II, Photo #5
5-2	Drain hole approx. 5 ft. South of Tendon 5-3; see Appendix II, Photo #5
5-3	Rock joint and plastic conduit approx. 7 ft. above Tendon 5-3; see Appendix II, Photo #6
5-4	Rock joint and plastic conduit approx. 7 ft. above Tendon 5-3

Table II-1. Half-Cell Locations (cont.)

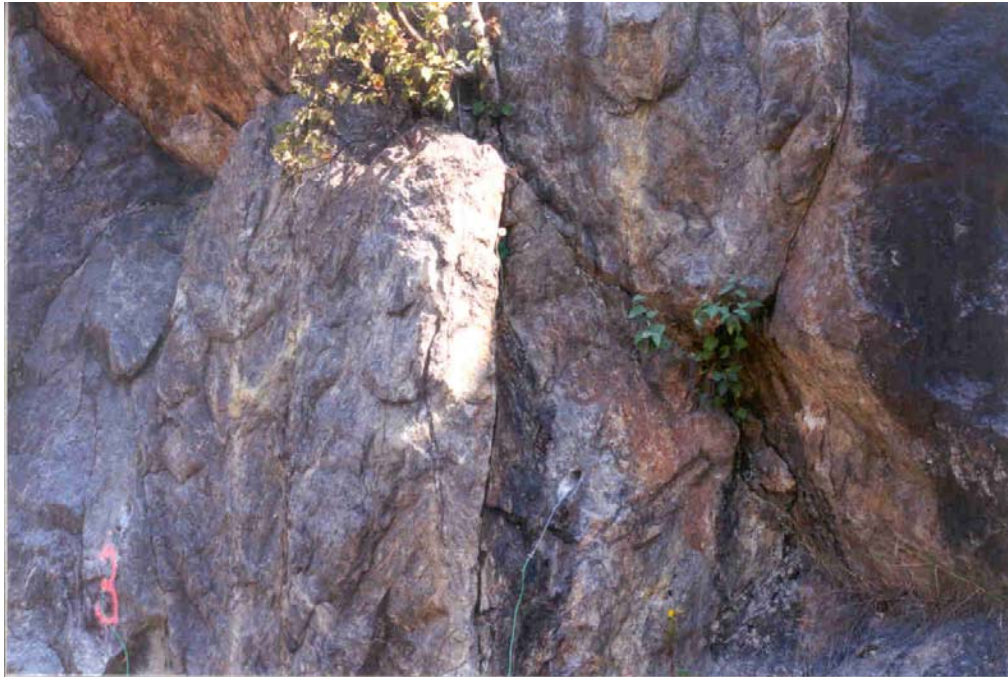
Rock Bolt #	Half-Cell Location
1	Drill-hole 8 in. South of Bolt 2; see Appendix II, Photo #7
2	Drill-hole 8 in. South of Bolt 2; see Appendix II, Photo #7
3	Rock joint between bolts 3 and 4; see Appendix II, Photo #8
4	Rock joint between bolts 3 and 4; see Appendix II, Photo #8
5	Approx. 10 ft. North of Tendon 2-3
6	Approx. 10 ft. North of Tendon 2-3
7	Approx. 3 ft. South and above Bolt 8
8	Approx. 3 ft. South and above Bolt 8
9	Approx. 1.5 ft above Bolt 9; see Appendix II, Photo #9
10	Approx. 1.5 ft above Bolt 9; see Appendix II, Photo #9
11	Drill-hole below Bolt 11; see Appendix II, Photo #10
12	Drill-hole below Bolt 11; see Appendix II, Photo #10
13	Drill hole south of Bolt 14; see Appendix II, Photo #11
14	Drill hole south of Bolt 14; see Appendix II, Photo #11
15	Rock joint approx. 8 ft. above and South of Bolt 15; see Appendix II, Photo #12
16	Rock joint approx. 8 ft. above and South of Bolt 15; see Appendix II, Photo #12
17	Rock joint approx. 10 ft. South of Bolt 18; see Appendix II, Photo #13
18	Rock joint approx. 10 ft. South of Bolt 18; see Appendix II, Photo #13
19	Rock joint above and South of Bolts 19, 20; see Appendix II, Photo #14 and 15
20	Rock joint above and South of Bolts 19, 20; see Appendix II, Photo #14 and 15
21	Crevice North of bolt 21; see Appendix II, Photo #16
22	Crevice North of bolt 21; see Appendix II, Photo #16



Photograph 1 – Half-cell location for Tendons 1-3 and 1-4.



Photograph 2 – Half-cell location for Tendon 2-4



Photograph 3 – Half-cell location for Tendons 3-1 and 3-2. Half-cell is placed in approximately two-thirds of the way up the crevice in the center of the photograph.



Photograph 4 – Half-cell location for Tendons 4-1 and 4-2. Half-cell is located at the intersection of the vertical and horizontal crevices in the center of the photograph.



Photograph 5 – Half-cell location for Tendons 5-1 and 5-2. Half-cell is placed in the hole directly above the water stain (right).



Photograph 6 – Half cell location for Tendons 5-3 and 5-4. Half-cell is placed beneath the black cable conduit approximately three-quarters of the way up the vertical section located in the center of the photograph.



Photograph 7 – Half-cell location for Bolts 1 and 2. Half-cell was placed in a hole to the right of Bolts 1 and 2 (center).



Photograph 8– Half-cell location for Bolts 3 and 4. Half-cell was placed in a vertical hole between Bolts 3 and 4 (center).



Photograph 9 – Half-cell location for Bolts 9 and 10. Half-cell was placed in a hole directly above Bolt 9 (center).



Photograph 10 – Half cell location for Bolts 11 and 12. Half-cell was placed in a hole between and below Bolts 11 and 12 (lower center).



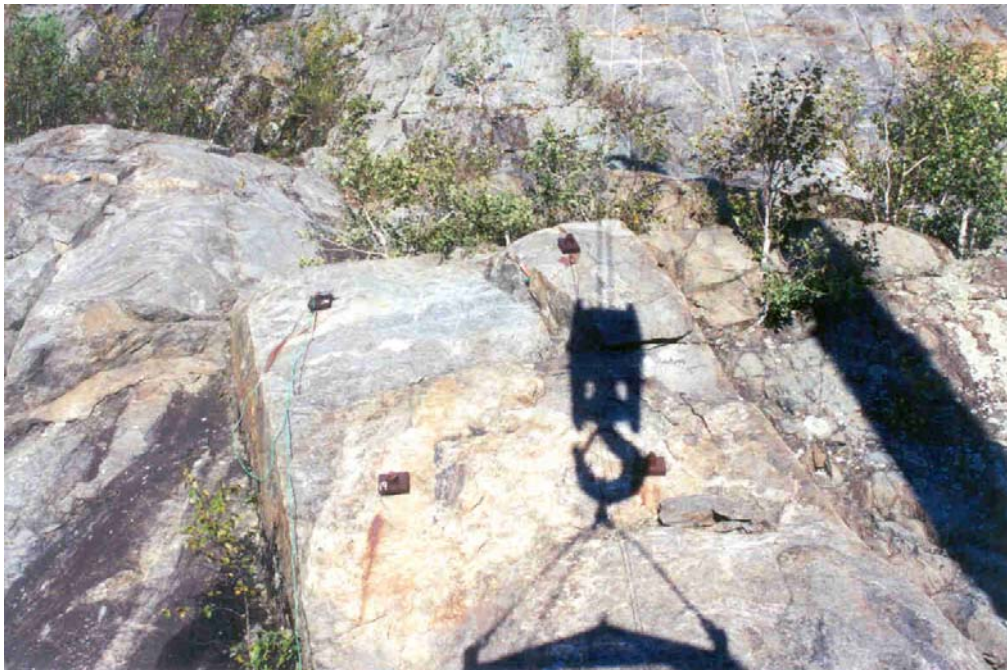
Photograph 11 – Half-cell location for Bolts 13 and 14. Half-cell was placed in a hole to the right of Bolts 13 and 14 (left center).



Photograph 12 – Half-cell location for Bolts 15 and 16. Half-cell was placed in the horizontal crevice, right of the near vertical crevice, in the center of the photo.



Photograph 13 – Half-cell location for Bolts 17 and 18. Half-cell was placed in a small crack approximately 10 feet to the right of Bolt 18.



Photograph 14 – Half-cell location for Bolts 19 and 20. Half-cell was placed in the crack approximately 10 feet to the right of Bolt 20.



Photograph 15 - Half-cell location for Bolts 19 and 20. Half-cell was placed in the crack approximately 10 feet to the right of Bolt 20.



Photograph 16 – Half-cell location for Bolts 21 and 22. Half-cell was placed in the crack approximately 3 feet to the left of Bolt 21.

APPENDIX III

LAB TEST RESULTS FROM NHDOT

Sample

Tag #90

- STATION 75+25

- Elevation 6' From
bottom of ditch

Mr. Dickerman, Rick
of New Hampshire - DOT
Date: 09/02/2003 Time: 10:24:54

Result entry for 1 sample from c:\ims\user\~ps1.tmp
Result entry template: ACROSS
Page: 1

User Info			Sample	AA11021
			Loc Code	GRAVEL
			Descript	Gravel Fine &
			PROJECT	
			JOB MIX	
			CYLINDER	
REMARK	Remarks		Result	
WTCOR	dry weight coarse Agg - Soils	lb	Result	3.38
SIV_A1	Elison 6" (150 mm) sieve	lb	Result	0
SIV_F1	Elison 3" (75 mm) sieve	lb	Result	0
SIV_H1	Elison 2" (50 mm) sieve	lb	Result	0
SIV_I1	1 1/2" (37.5 mm) sieve	lb	Result	0
SIV_K1	1" (25 mm) sieve	lb	Result	0
SIV_L1	3/4" (19 mm) Sieve	lb	Result	0
SIV_M1	1/2" (12.5 mm) Sieve	lb	Result	.05
SIV_O1	#4 (4.75 mm) Sieve	lb	Result	.33
WTFN	dry weight fine Agg - Soils	gm	Result	499.5
SIV_R3	#8 (2.0 mm) sieve	gm	Result	66.1
SIV_S3	#20 (0.850 mm) sieve	gm	Result	181.7
SIV_U3	#40 (0.425 mm) sieve	gm	Result	292.7
Y3	#100 (0.150 mm) sieve	gm	Result	412.4
Z3	#200 (0.075 mm) sieve	gm	Result	465.4
SVA1P	6 in (150 mm) Sieve	% Pass in	Result	100.0
SVF1P	3 in (75 mm) Sieve	% Pass in	Result	100.0
SVH1P	2 in (50 mm) Sieve	% Pass in	Result	100.0
SVI1P	1 1/2 in (37.5 mm) Sieve	% Pass in	Result	100.0
SVK1P	1 in (25 mm) Sieve	% Pass in	Result	100.0
SVL1P	3/4 in (19 mm) Sieve	% Pass in	Result	100.0
SVM1P	1/2 in (12.5 mm) Sieve	% Pass in	Result	98.5
SVO1P	#4 (4.75 mm) Sieve	% Pass in	Result	90.2
SVR3P	No 10 (2.00 mm) Sieve	% Pass in	Result	86.8
SVS3P	No 20 (0.850 mm) Sieve	% Pass in	Result	63.6
SVU3P	No 40 (0.425 mm) Sieve	% Pass in	Result	41.4
SVY3P	#100 (0.150 mm) Sieve	% Pass in	Result	17.4
SVZ3P	#200 (0.075 mm) Sieve	% Pass in	Result	6.8
ANALYST	Tested By:		Result	
REVIEW	Reviewed by:		Result	

P.H. = 5.12
% Moisture 5.5

Sample # 2

73

- Station 76+85

- Elevation 15' from Bottom

Dickerman, Rick
 of New Hampshire - DOT
 Date: 09/02/2003 Time: 10:32:34

Result entry for 1 sample from c:\lms\user\~ps1.tmp
 Result entry template: ACROSS
 Page: 1

User Info	Sample	AA11034
	Loc Code	GRAVEL
	Descript	Gravel Fine &
	PROJECT	
	JOB MIX	
	CYLINDER	
REMARK	Remarks	Result
WTCOR	dry weight coarse Agg. & Soils	lb Result 2.54
SIV_A1	Gilson 6" 150 mm sieve	lb Result 0
SIV_F1	Gilson 8" 75 mm sieve	lb Result 0
SIV_H1	Gilson 2" 50 mm sieve	lb Result 0
SIV_I1	1 1/2" (37.5 mm) sieve	lb Result 0
SIV_K1	1" (25 mm) sieve	lb Result .04
SIV_L1	3/4" (19 mm) Sieve	lb Result .26
SIV_M1	1/2" (12.5 mm) Sieve	lb Result .54
SIV_O1	#4 (4.75 mm) Sieve	lb Result 1.07
WTFN	dry weight fine Agg. & Soils	gm Result 375.8
SIV_R3	8" no 10 sieve	gm Result 91.3
SIV_S3	8" no 20 sieve	gm Result 167.7
SIV_U3	8" no 40 0.425 mm sieve	gm Result 215.5
Y3	8" no 100 0.150 mm sieve	gm Result 277.1
SIV_Z3	8" no 200 0.075 mm sieve	gm Result 317.1
SVA1P	6 in (150 mm) Sieve	% Passin Result 100.0
SVF1P	8 in (75 mm) Sieve	% Passin Result 100.0
SVH1P	2 in (50 mm) Sieve	% Passin Result 100.0
SVI1P	1 1/2 in (37.5 mm) Sieve	% Passin Result 100.0
SVK1P	1 in (25 mm) Sieve	% Passin Result 98.4
SVL1P	3/4 in (19 mm) Sieve	% Passin Result 89.8
SVM1P	1/2 in (12.5 mm) Sieve	% Passin Result 78.7
SVO1P	#4 (4.75 mm) Sieve	% Passin Result 57.9
SVR3P	No 10 (2.00 mm) Sieve	% Passin Result 75.7
SVS3P	No 20 (0.850 mm) Sieve	% Passin Result 55.4
SVU3P	No 40 (0.425 mm) Sieve	% Passin Result 42.7
SVY3P	#100 (0.150 mm) Sieve	% Passin Result 26.3
SVZ3P	#200 (0.075 mm) Sieve	% Passin Result 15.6
ANALYST	Tested By:	Result
REVIEW	Reviewed by:	Result

P.H. = 4.24

% Moisture
 3.9%

DATE: October 20, 2003
PROJECT: Barron Mountain Rock Reinforcement Evaluation, Woodstock, NH
PROJECT NO.: 13733L

APPARATUS:

Iris Instruments -- Syscal Jr. Switch 48	4-Probe plexiglas test box
Mode -- Rho mode	AB/2 = 0.36 ft.
Electrical Array -- Schlumberg sounding	MN = 0.42 ft. = 12.8 cm.
Measurement Time -- 1000 msec	Line = 0.71 ft. = 21.6 cm
Stacks -- 3	K = 1 per resistivity test box literature
V=MilliVolts	
I=MilliAmps	

TEST SAMPLE: Location -- Station 1777+00 Air Dry Weight = 1500 gms.
Natural Moisture = 7.2%

	Distilled Water (ml.)		Resistivity Data			Min. Average
	Increment	Cumm.	V	I	Ro (ohm-cm)	Ro (ohm-cm)
Sample #2	160	160	2107.472	0.5	4215	6685.5
	90	250	2343.284	0.12	19527	
	100	350	2496.782	0.23	10856	
	100	450	2671.145	0.35	7632	
	100	550	2580.444	0.38	6791	
	100	650	2566.336	0.39	6580	

TEST SAMPLE: Location -- Station 1775+50 Air Dry Weight = 1500 gms.
Natural Moisture = 13.0%

	Distilled Water (ml.)		Resistivity Data			Min. Average
	Increment	Cumm.	V	I	Ro (ohm-cm)	Ro (ohm-cm)
Sample #1	150	150	2342.509	0.08	29281	10392
	100	250	2415.687	0.15	16105	
	100	350	2548.289	0.24	10618	
	100	450	2589.276	0.27	9590	
	100	550	2632.086	0.24	10967	

NHDOT Laboratory Report
Barron Mountain Rock Reinforcement Evaluation -- 13733L
November 2003

WATER

TEST	Sample #1	Sample #2
pH	6.92	6.39
Cl ⁻	6ppm	6 ppm
Mg ⁺	0.833 ppm	1.48 ppm
SO ₄	5.76 ppm	13.2 ppm

SOIL

TEST	Sample #1	Sample #2
Cl ⁻	0.072%lbs Cl ⁻ /yd ³ (720 ppm)	0.025%lbs Cl ⁻ /yd ³ (250 ppm)
Mg ⁺	0.27% (2702 ppm)	0.48% (4793 ppm)
SO ₄	652 ppm	ND



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professional laboratory services

Fax Cover Sheet

PRELIMINARY ANALYTICAL RESULTS

Fax results have not been subjected to a final QA/QC review.
If you have any questions on faxed data, please contact us.

To: Denis Boisvert

EAI ID#: 38432

Company: New Hampshire Dept of

Client ID: Barron Mountain, Woodstock / 13733L

Company FAX: 603 271-8700

Date Received: 9/19/2003

Project Manager FAX:

New Hampshire Dept of Transportation FAXing Info: None

Denis Boisvert FAXing Info: None

9/23/03

Complete Report: opgs

Partial Report: Wet Chem Met VOC TPH COC

Invoice Pest/PCB ABN/PAH EPH Field SUB

Upcoming Events

19th Contaminated Soils, Sediments & Water

October 20-23, 2003

Annual Conference

University of Massachusetts at Amherst

visit us at our booth

for more information call 413-545-1239

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LABORATORY REPORT

Eastern Analytical, Inc. ID#: 38432

Client: New Hampshire Dept of Transportation Client Designation: Barron Mountain, Woodstock / 13733L

Sample ID: #1 Sta. 1774 + 70 #2 Sta. 1777 +
00

Matrix: aqueous aqueous
Date Sampled: 9/11/03 9/11/03
Date Received: 9/19/03 9/19/03
Ammonia < 0.05 < 0.05

Units	Date of Analysis	Method	Analyst
mg/L	9/22/03	350.3	KL

APPENDIX IV

DETAILED CALCULATIONS FOR SERVICE LIFE ESTIMATES

Assessment of Corrosion Potential

Laboratory Test Results

Weathered Rock.

Test data submitted by NHDOT are included in Appendix III. Table IV-1 is a summary of the results from testing samples of weathered rock.

Table IV-1. Summary of Laboratory Test Results for Weathered Rock

Sample #	% Pass #4	%Pass #200	w %	pH	Resist. Ω -cm	SO ₄ ppm	Cl- ppm
1	90.2%	6%	13	5.1	9590	652	720
2	57.9%	9%	7	4.2	4215	ND	250

These results will be used to access the aggressiveness of the environment relative to corrosion of the rock bolts. The Recommendations Clouterre (FHWA, 1993) considers four main assessment parameters used to evaluate the corrosiveness of soils, including type of soil, soil resistivity, moisture content and pH. Each parameter is assigned a numerical weight, as shown in Table IV-2, that depends on features of the soil. The corrosiveness of the soil is shown as a global index ΣA , obtained from adding together the weighting factors for each of the four evaluation criteria. The last column in the table corresponds to conditions at the Barron Mountain site where the weathered rock samples are described as a sandy cohesionless soil, with resistivity greater than 5000 Ω -cm, seeping joints corresponding to a variable water table, and pH between 4 and 5.

Table IV-2. Overall Corrosiveness Index (Clouterre, 1991)

Criterion	Features	Weight A of Criterion	Barron Mtn.
Type of Soil	Texture - heavy, plastic, sticky impermeable - clayey-sand - light, permeable, sandy, cohesionless soils Peat and bog/marshlands Industrial Waste - clinker, cinders, coal - builder's waste (plaster, bricks) Polluted Liquids - wastewater, industrial - water containing de-icing salts	2 1 0 8 8 4 6 8	0
Resistivity	< 1000 Ω -cm 1000 Ω -cm to 2000 Ω -cm 2000 Ω -cm to 5000 Ω -cm > 5000 Ω -cm	5 3 2 0	0
Moisture Content	Water table- brackish water (variable or permanent) Water table – pure water (variable or permanent) Above water table moist soil (water content > 20%) Above water table dry soil (water content < 20%)	8 4 2 0	4
pH	< 4 4 to 5 5 to 6 > 6	4 3 2 0	3
	Global Index	Sum of above: ΣA	7

The resulting global index is 7, which corresponds to average corrosiveness (Classification III) as shown in Table IV-3. If a resistivity less than 5000 Ω -cm is considered, the classification is degraded to II, corresponding to corrosive. Given the range of measurements for resistivity, the classification for the weathered rock is considered to be between II and III.

Table IV-3. Corrosiveness of Soils (Clouterre, 1991)

Index ΣA	Soil Features	Classification
>13	Highly corrosive	I
9 to 12	Corrosive	II
5 to 8	Average corrosiveness	III
< 4	Slightly corrosive	IV

Ground Water

The following is a summary of the measurements made on sample #1 and #2 on Thursday, September 11, 2003 by MMCE during sample retrieval.

	pH	Temp.	
#1	5.78	27.9° C	From bolt hole ~ sta. 1774+75
#2	5.61	20.6° C	From well ~ sta. 1777+00

Table IV-4, from Xanthakos (1991), describes the range of parameters used for qualitatively assessing the potential aggressiveness of groundwater. Results from laboratory test performed by NHDOT, and presented in Appendix III, indicate that concentrations of magnesium, sulfate and ammonium ions in the groundwater are well below the limits described in Table IV-4. Based on these observations, a measured pH~5.6, and the information described in Table IV-4, the aggressiveness of the groundwater is considered weak.

Table IV-4. Parameter Limits for Aggressive Groundwater Conditions
(Modified after Xanthakos, 1991)

Test	Aggressiveness		
	Weak	Strong	Very Strong
pH	6.5-5.5	5.5-4.5	<4.5
Lime-dissolving CO ₂ , mg/l	15-30	30-60	>60
Ammonium (NH ₄ ⁺), mg/l	15-30	30-60	>60
Magnesium (Mg ²⁺), mg/l	100-300	300-1500	>1500
Sulfate (SO ₄ ²⁻), mg/l	200-600	600-3000	>3000

Estimated Remaining Service Life

The following equation, proposed by Romanoff (1957), is used to estimate corrosion rate and corresponding service life of buried metal reinforcements:

$$X = Kt^r \quad (IV-1)$$

where,

X = loss of reinforcement thickness or radius (μm)

K = constant (μm)

t = time (years)

Equation IV-1 assumes that attack from the surrounding environment is immediate and unaffected by the presence of grout around the metal. In reality, some measure of corrosion protection is afforded to the metal reinforcements by the surrounding grout. Therefore the following calculations are considered conservative estimates of remaining service life and loss of cross section.

The appropriate parameters for use in the rate equation are based on the corrosiveness index of the weathered rock samples collected from the Barron Mountain site. According to the recommendations described in NCHRP (2002), the parameters “K” and “r” for use in the rate equation are adjusted relative to soil conditions as summarized below.

Table IV-5. Recommended Parameters for Service Life Prediction Model (NCHRP, 2002)

Parameter	Average	Corrosive	Highly Corrosive
K (μm)	35	50	340
r	1.0	1.0	1.0

Based on the measurements of resistivity and pH, and the hydrogeologic conditions at the Barron Mountain site, the corrosiveness of the environment is described as average for the purpose of estimating service life. Therefore, values of $K = 35 \mu\text{m}$ and $r = 1$ will be used to estimate the loss of cross section and service life of rock bolts and tendons installed at the site. However, the computed service-life will also consider the possibility of localized, pitting type corrosion due to the relatively low pH measured for the weathered rock samples.

For environments with a $\text{pH} < 5$, where high strength steels are used, the effect of pitting corrosion needs to be considered. This is considered by multiplying the loss of reinforcement thickness, X, computed with the rate equation by a factor of two for estimation of remaining service-life (this presumes that the loss of tensile

strength is approximately two times the average loss of section due to the effects of localized corrosion (Elias, 1990)).

Calculations for 1" Rock Bolts

Two types of rock bolts were used at the Barron Mountain site including 1-in diameter, polyester resin grouted bolts supplied by Bethlehem Steel Co., and 1-in diameter, polyester resin grouted Dywidag bolts supplied by Inland-Ryerson Steel Co. The Bethlehem bolts are made from Grade 80 steel and the Dywidag bolts are Grade 150 steel. Working loads are 20 kips and 40 kips for the Bethlehem and Dywidag bolts, respectively. If one considers an allowable load equal to 60% of the yield stress for the Bethlehem bolts, and 60% of the guaranteed ultimate tensile for the Dywidag bolts, then the required radius for each is approximately 0.364 inches and 0.376 inches, respectively. Therefore, approximately 0.124 inches (3150 μ m) of steel thickness can be sacrificed to corrosion given an average radius of 0.5 inches for each bolt. From Equation IV-1, with $K = 35$, $r = 1$, and the factor of 2 for pitting corrosion:

$$2(K)t = 3150$$

Hence, $t = 45$ years.

Therefore, remaining service life = $t - \text{age} = 45 - (2003-1972) = 14$ years.

Considering the age of the reinforcements, Equation IV-1 indicates up to 0.043 inches of steel may have been consumed by corrosion. This corresponds to a loss of cross section of approximately 16%. This amount of loss of cross section is considered to be close to the sensitivity of NDT measurements.

Calculations for 1.25" Rock Tendons

The steel tendons are 1.25-in diameter, Grade 150 ksi (1030 MPa) steel, Dywidag thread bars, fully grouted in 3-in diameter drill holes. The reinforcement cross sections do not include sacrificial thickness, and, apparently, rely on the surrounding Portland cement grout to passivate and protect the steel from corrosion. According to this strategy, the service-life of these reinforcements corresponds to the integrity and the thickness of the Portland cement grout surrounding the reinforcements.

However, the possibility of chloride contamination of the Portland cement grout exists, which may depassivate the steel and initiate corrosion. The time for initiation of corrosion in the presence of chlorides depends on the concentration of chlorides at the grout/rock interface, and the diffusivity and thickness of the grout surrounding the tendon. If the bars are centrally located within the three-inch diameter drill holes, they are protected by approximately 0.875 inches of grout. This amount of cover should provide at least 50 years of protection (since installation), given the subsurface conditions at the Barron Mountain site.

However, during the condition assessment, MMCE observed that not all of the reinforcements are centrally located within the drill hole. Because the ability of the Portland cement grout to protect the steel tendons is uncertain, we will estimate the “time to failure” of the reinforcements assuming they are unprotected.

The rock tendons are not prestressed, but it is assumed that passive resistance corresponding to the allowable stress levels in the reinforcements may be generated in response to rock deformation. Based on strain measurements described by Haley & Aldrich (1976), some of the reinforcements may be loaded to the allowable stress level of 60% of the minimum specified tensile strength (F_{PU}). For the purpose of illustration, we estimate the time for unprotected reinforcements to corrode to failure as follows:

1. Compute the critical radius as described by Briaud et al. (1998), corresponding to a reduction in cross sectional area to a level where failure will occur by overload. This calculation assumes that stress levels beyond 60% of F_{PU} are allowed by NHDOT. As described by ASTM A-722, the minimum specified tensile strength of the tendon is 150 ksi (1035 MPa). Assuming the tendon is loaded to 60% of the UTS under a constant load, the magnitude of the constant load can be calculated as $F = 0.6 * (150 \text{ ksi}) * (\pi d^2/4)$. Given the diameter of the bar, $d = 1.25 \text{ in}$ (32 mm), $F = 0.6 * 150 * (\pi * 1.25^2/4) = 110 \text{ kips}$. Therefore:

$$UTS = 150(\text{ksi}) = \frac{110(\text{kips})}{\pi r_{\text{critical}}^2} \rightarrow r_{\text{critical}} = 0.483(\text{in}) = 12.27(\text{mm})$$

The critical radius computed above represents a symmetrical loss of thickness of the reinforcement equal to $32 \text{ mm}/2 - 12.27 \text{ mm} = 3.73 \text{ mm} = 3730 \mu\text{m}$.

2. From Equation IV-1, with $K = 35$, $r = 1$ and the factor of 2 for pitting corrosion:

$$2(K)t = 3730$$

Hence, $t = 53 \text{ years}$.

Therefore, the estimated “time to failure” of unprotected tendons = $t - \text{age} = 53 - (2003-1972) = 22 \text{ years}$.

Considering the age of the reinforcements, the service life Equation IV-1 indicates up to 0.043 inches of steel may have been consumed by corrosion. This corresponds to a loss of cross section for the tendons of approximately 13%.

APPENDIX V

POLARIZATION CURVES

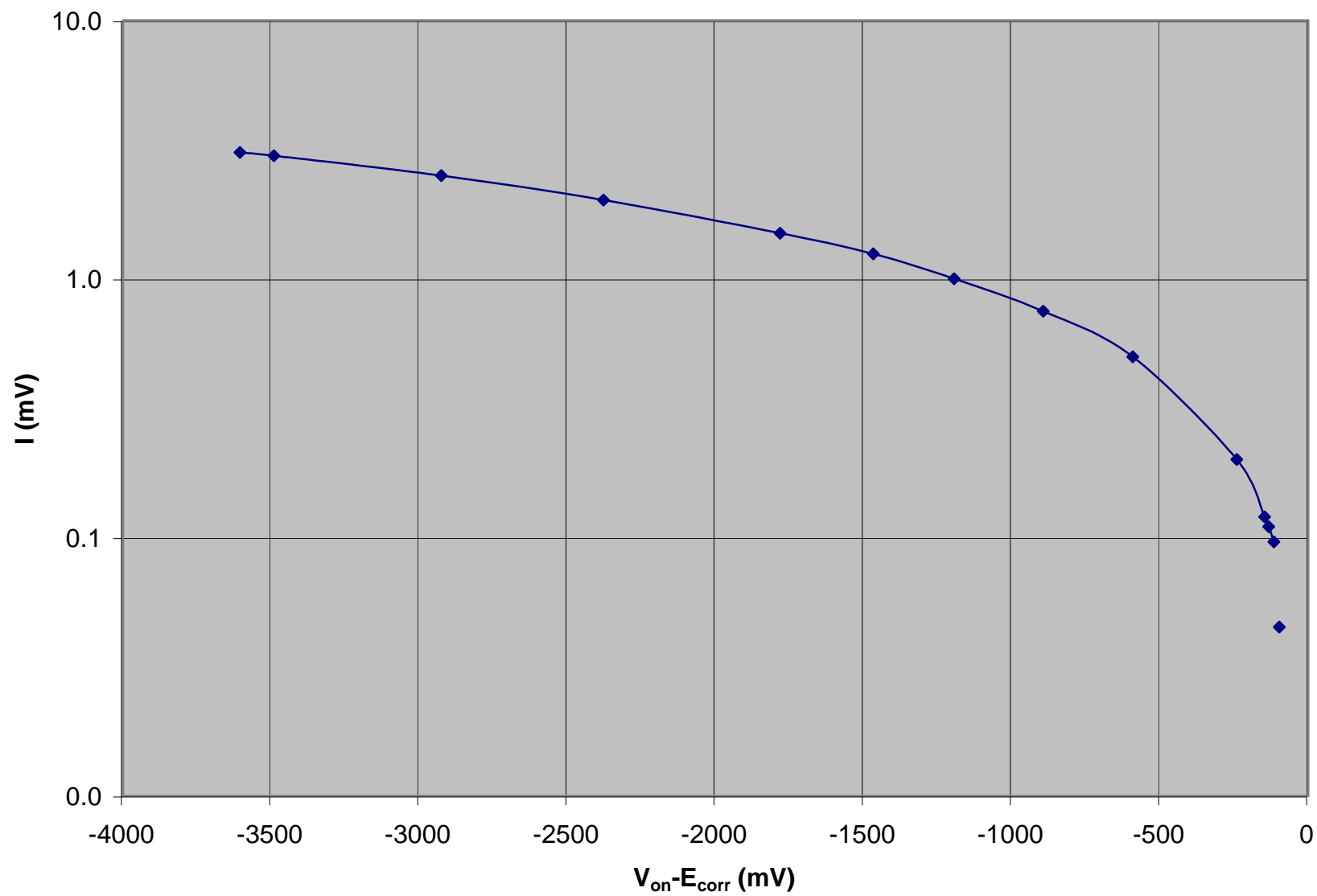
Table V-1. Summary of Polarization Current.

Rock Bolt #	I _p (mA)	Length (ft)	I _p /L (mA/ft)
1	1.50	15	0.10
2	1.50	25	0.06
3	0.85	25	0.03
4	1.75	30	0.06
5	1.50	25	0.06
6	1.00	15	0.07
7	1.25	10	0.13
8	0.70	10	0.07
9	0.50	10	0.05
10	1.25	15	0.08
11	2.25	25	0.09
12	2.00	25	0.08
13	1.75	30	0.06
14	1.75	30	0.06
15	1.50	20	0.08
16	1.75	20	0.09
17	1.75	25	0.07
18	1.25	25	0.05
19	2.00	20	0.10
20	2.00	20	0.10
21	0.75	10	0.08
22	1.50	25	0.06

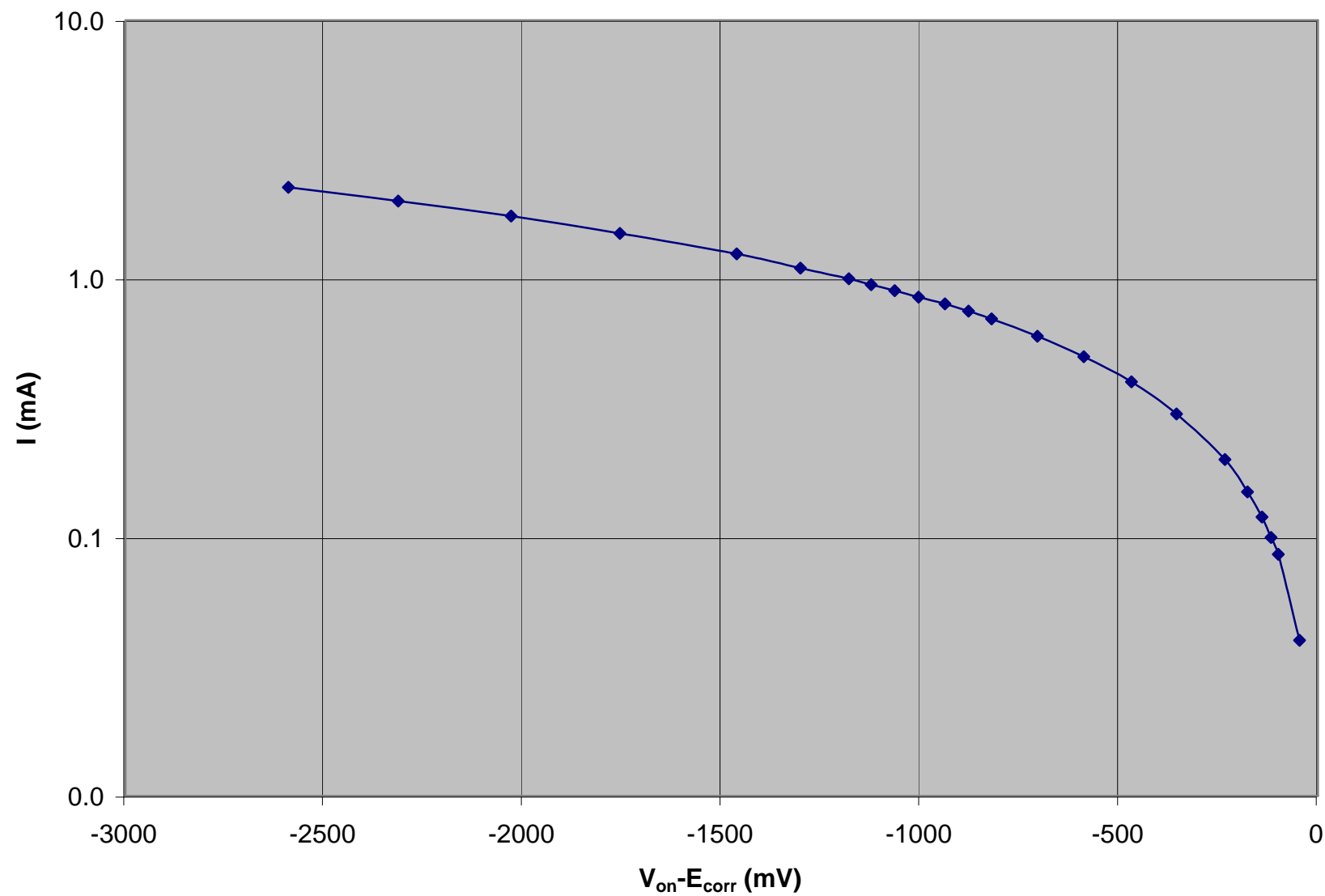
Table V-1. Summary of Polarization Current (cont.)

Tendon #	I _p (mA)	Length (ft)	I _p /L (mA/ft)
1-1	2.00	60	0.03
1-2	2.50	60	0.04
1-3	2.25	60	0.04
1-4	2.25	60	0.04
2-1	2.25	60	0.04
2-2	2.00	60	0.03
2-3	2.00	60	0.03
2-4	1.75	60	0.03
3-1	2.00	60	0.03
3-2	2.00	60	0.03
3-3	1.50	60	0.02
3-4	1.75	60	0.03
4-1	2.25	60	0.04
4-2	1.75	60	0.03
4-3	1.75	60	0.03
4-4	1.75	60	0.03
5-1	2.25	60	0.04
5-2	2.00	60	0.03
5-3	2.75	60	0.05
5-4	2.75	60	0.05

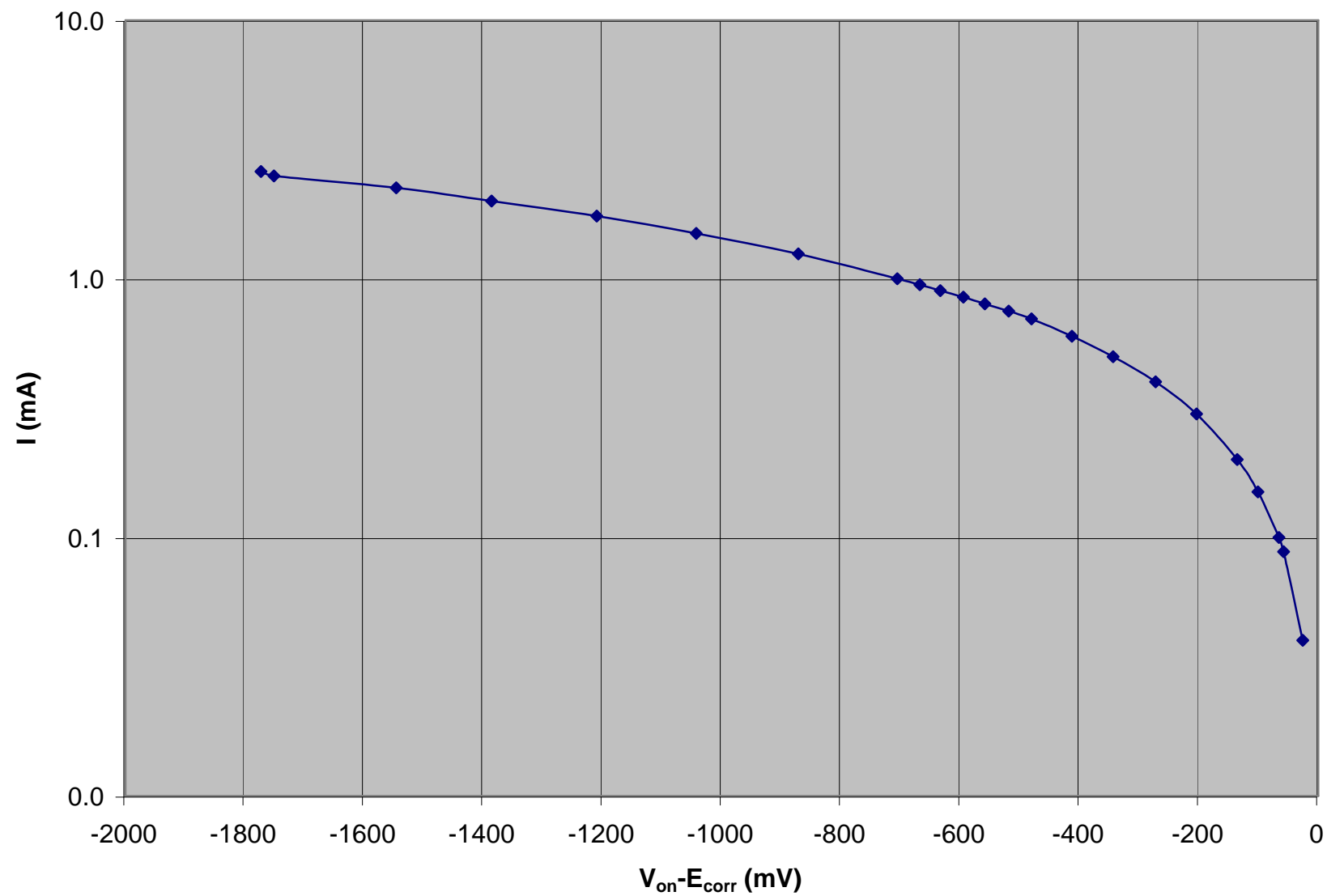
Bolt #1 - Test #1



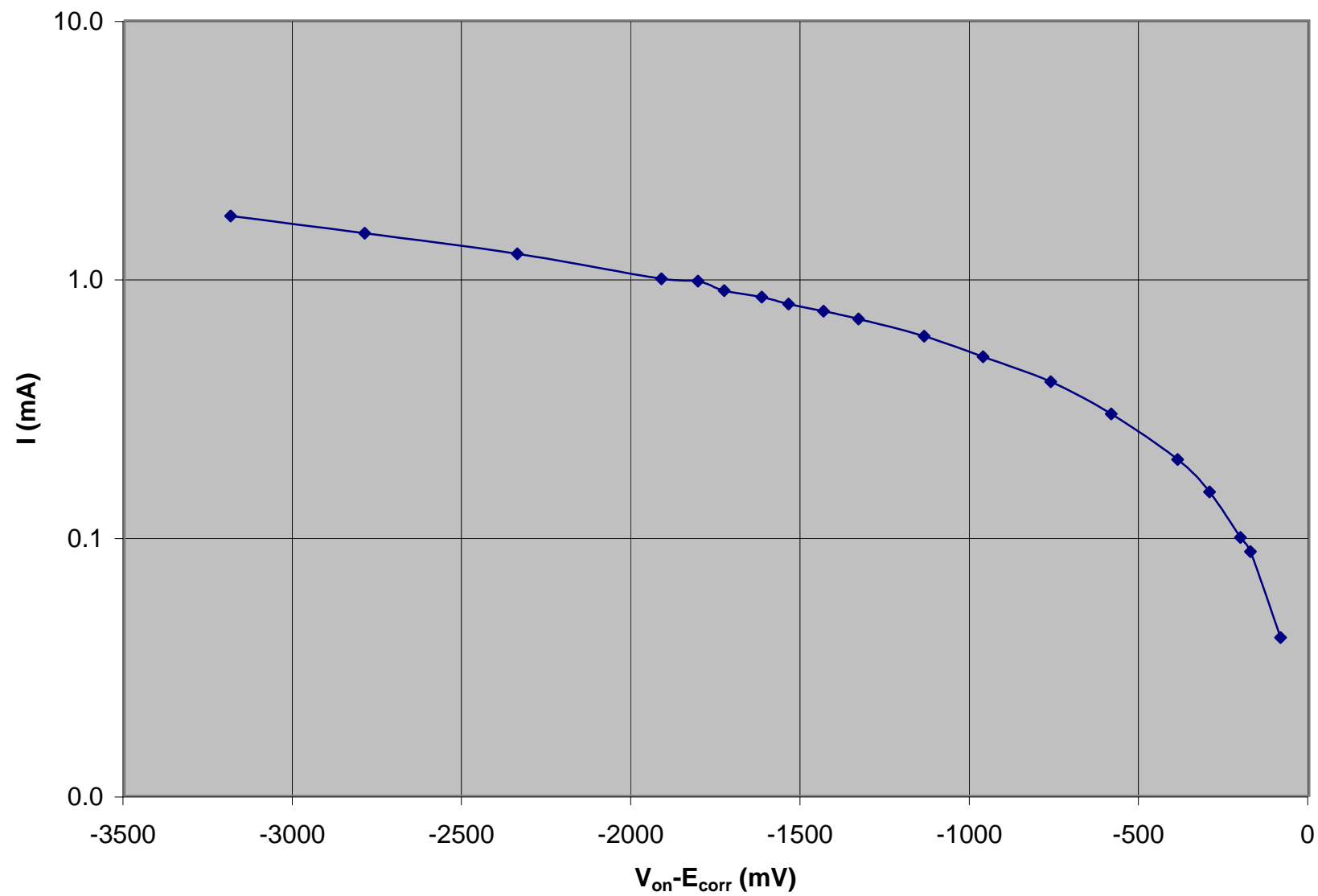
Bolt #1 - Test #2



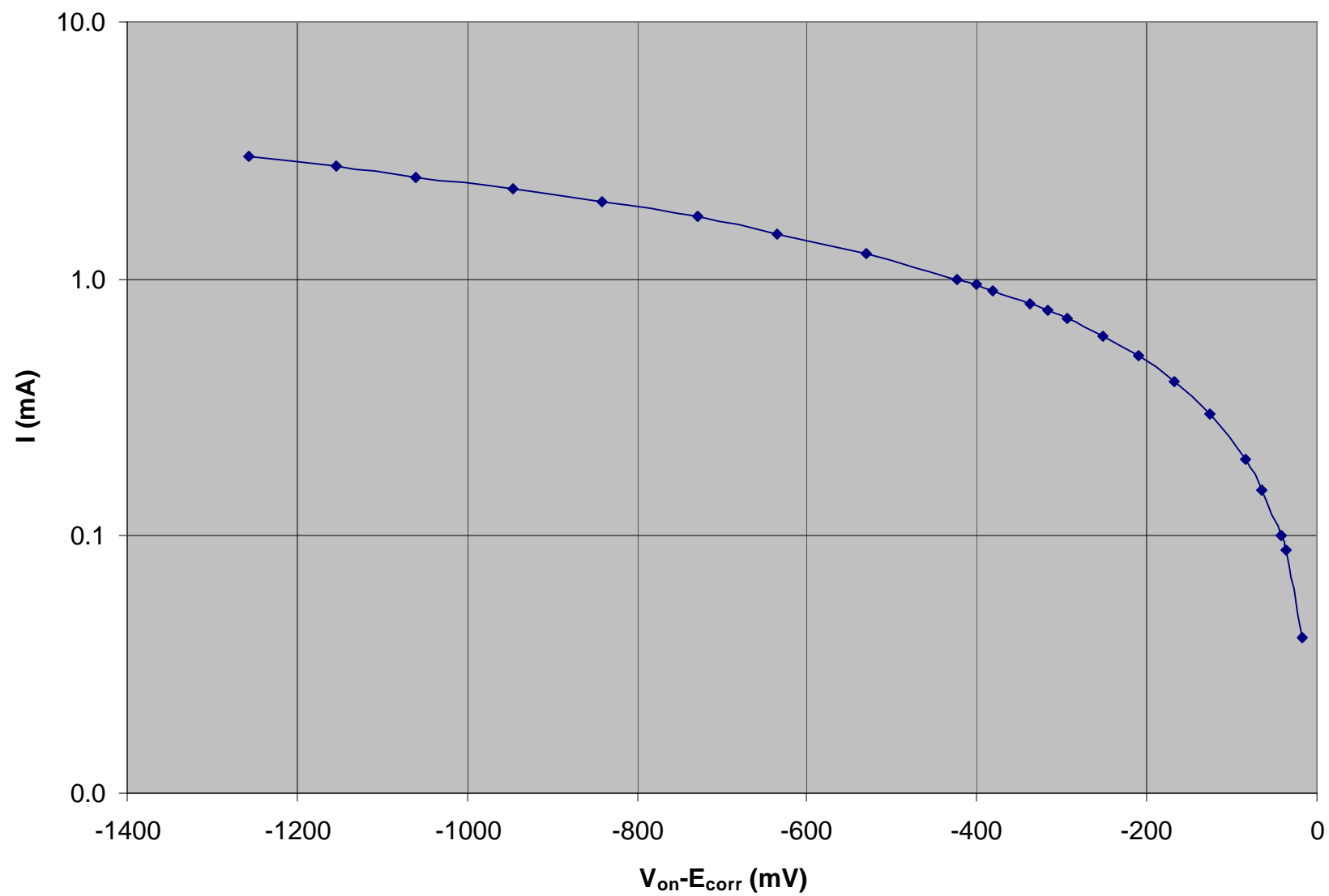
Bolt #2



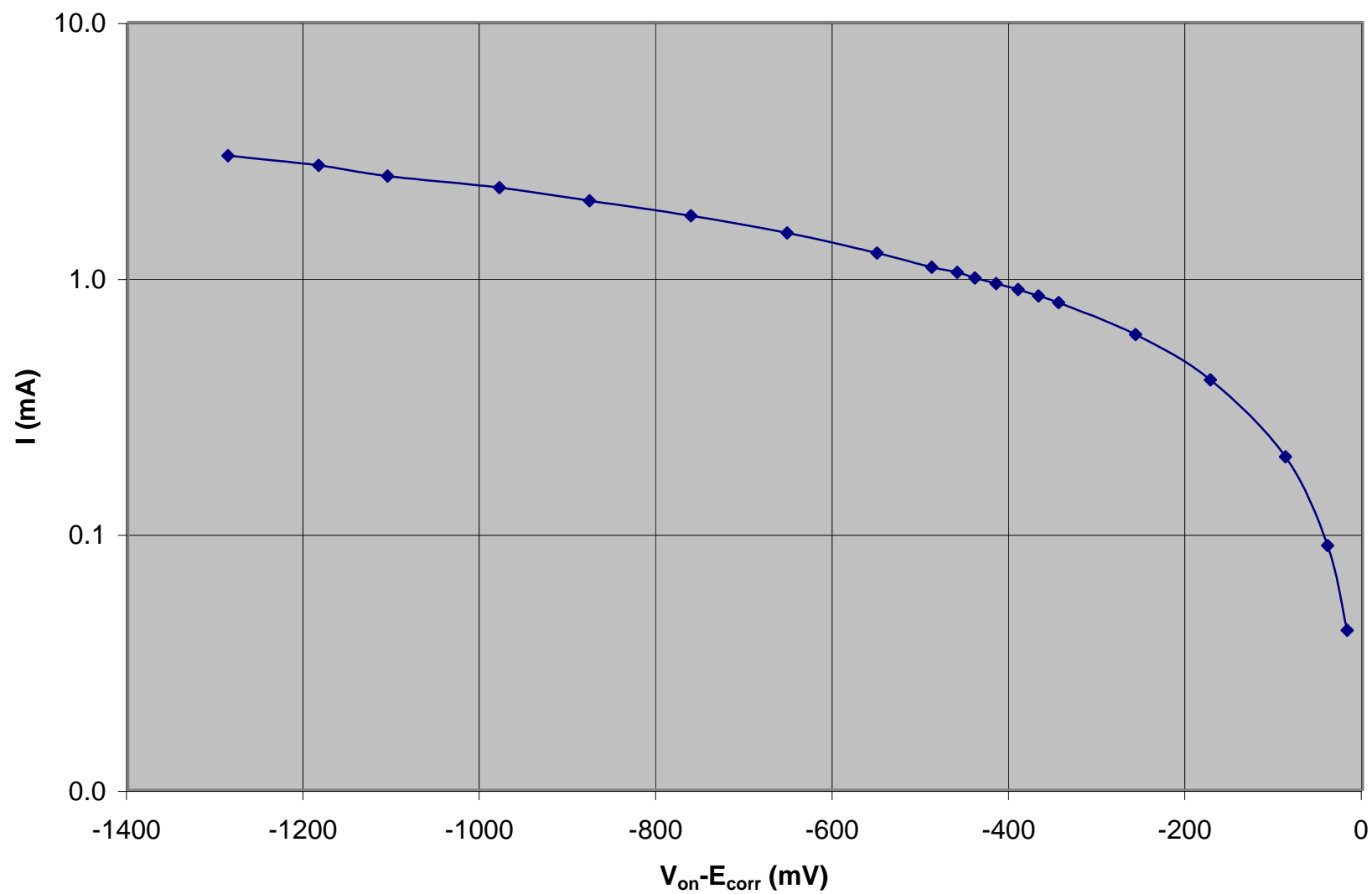
Bolt #3



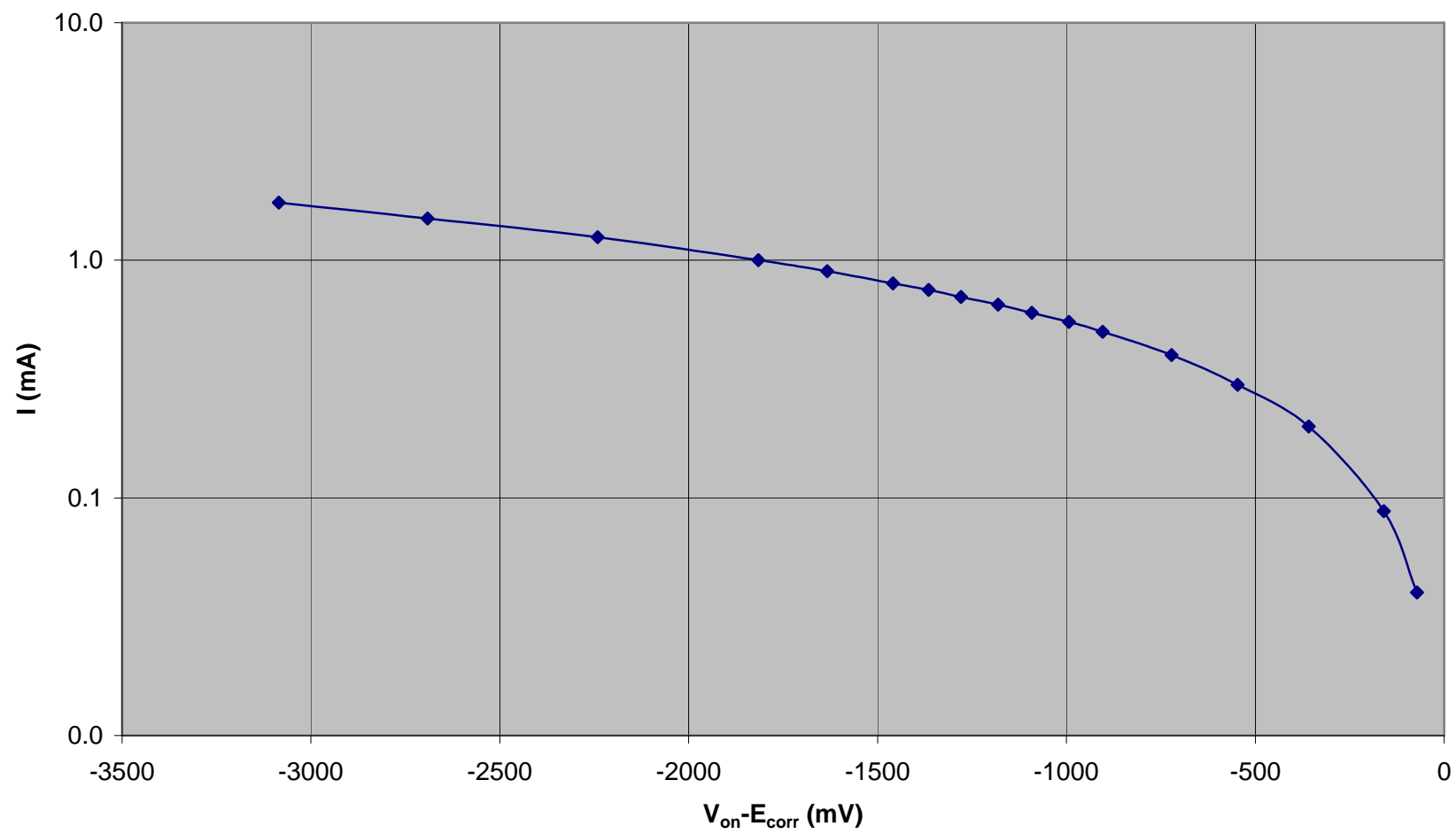
Bolt #4



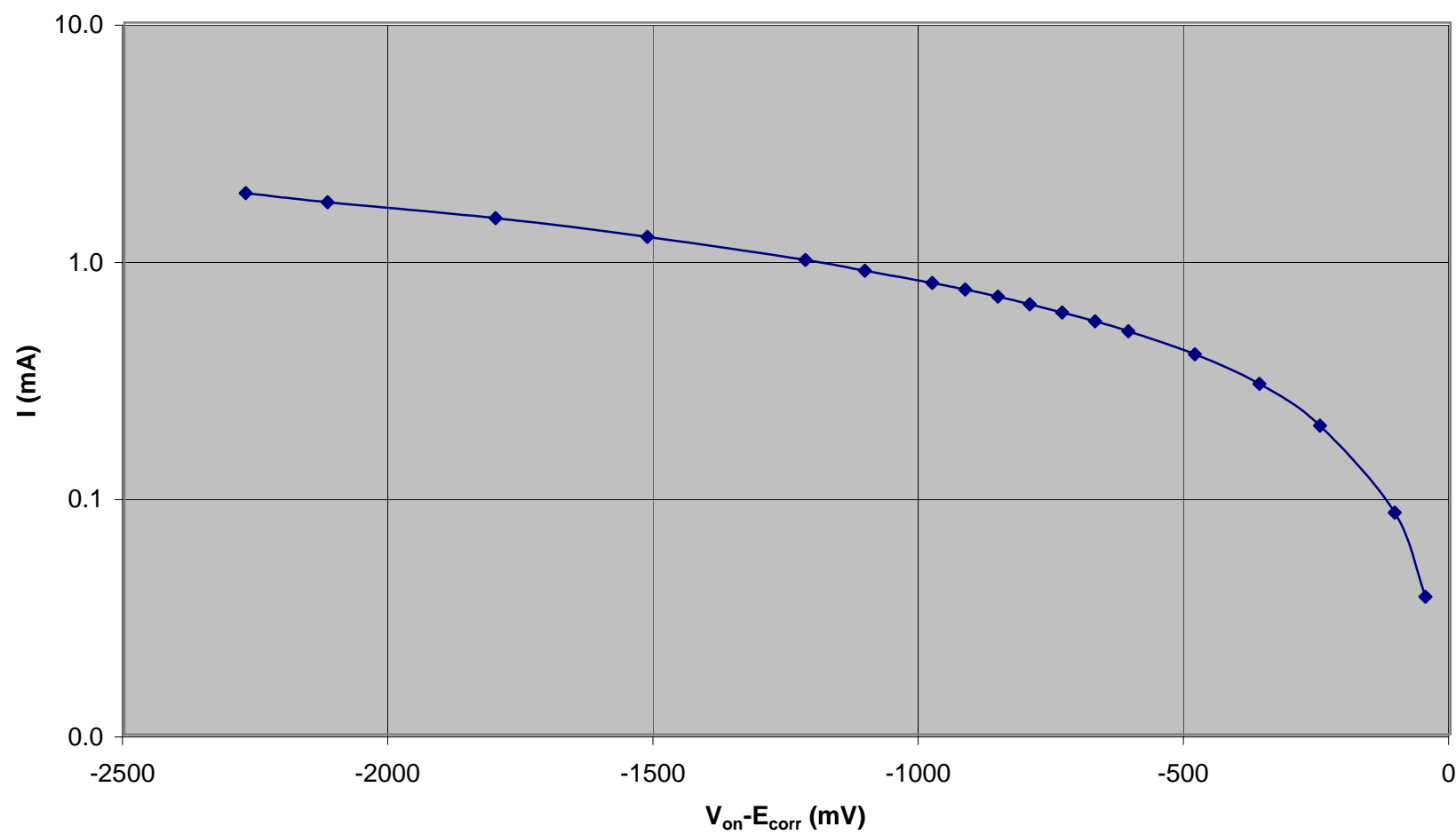
Bolt #5



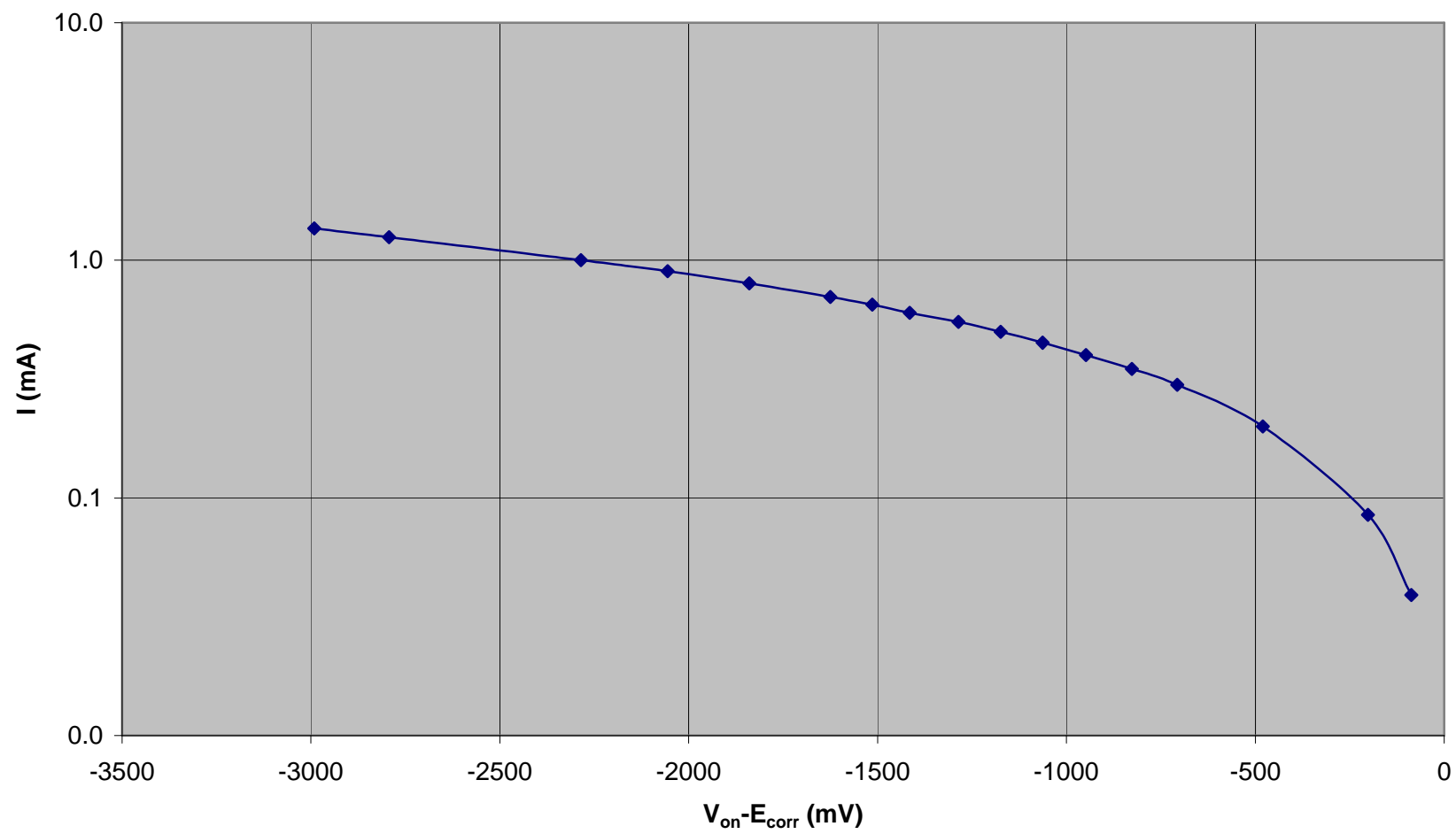
Bolt #6



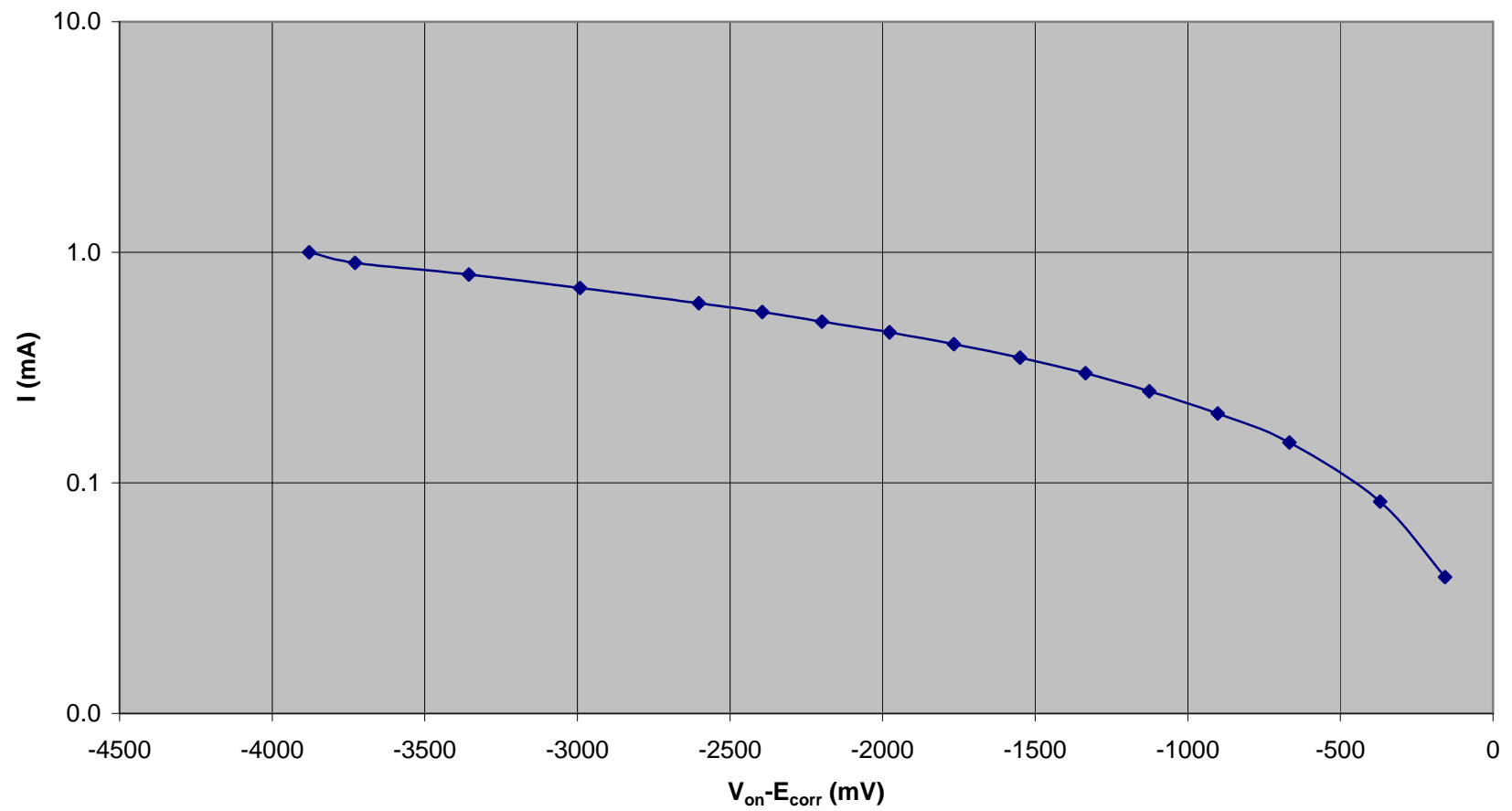
Bolt #7



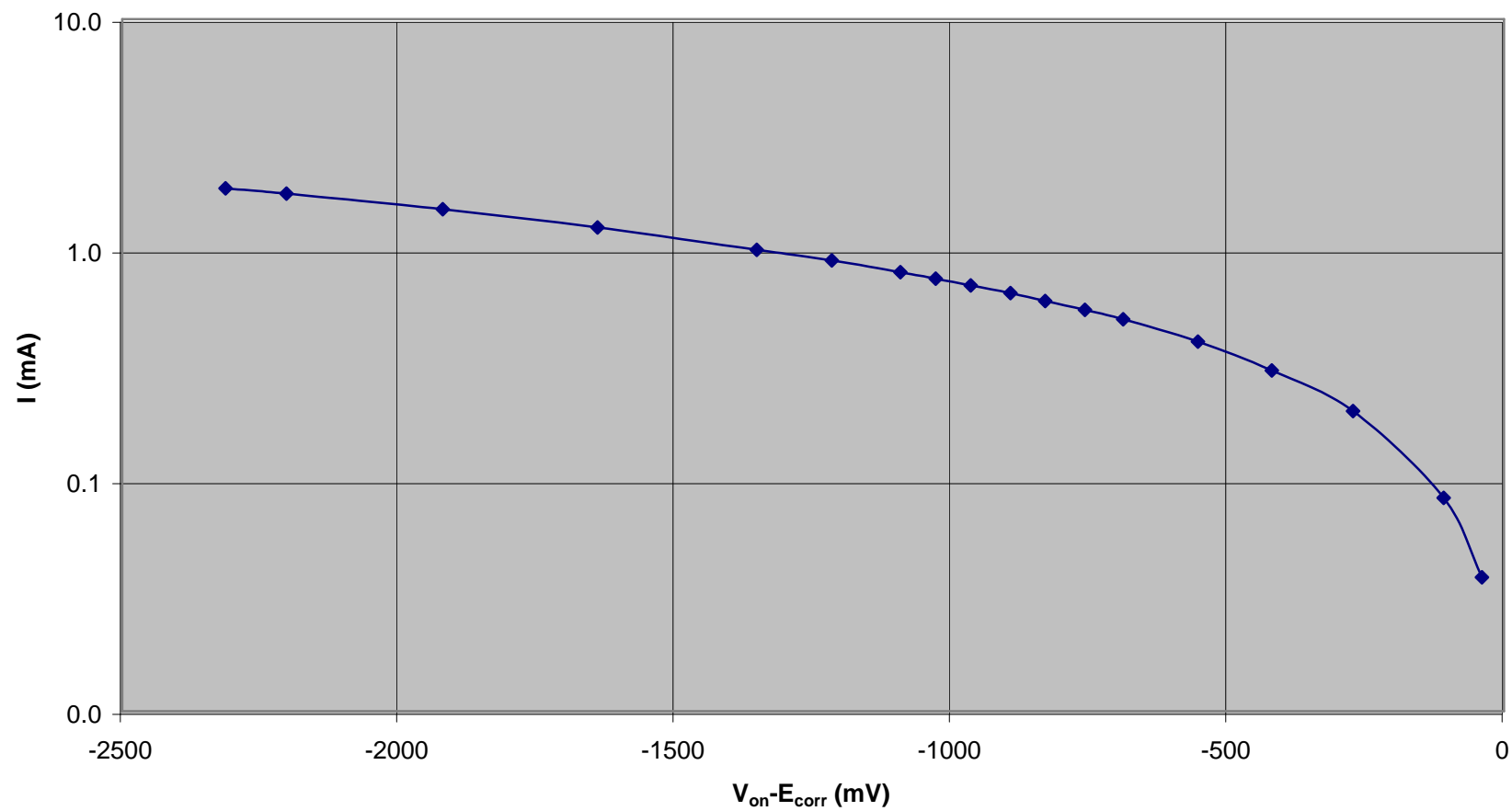
Bolt #8



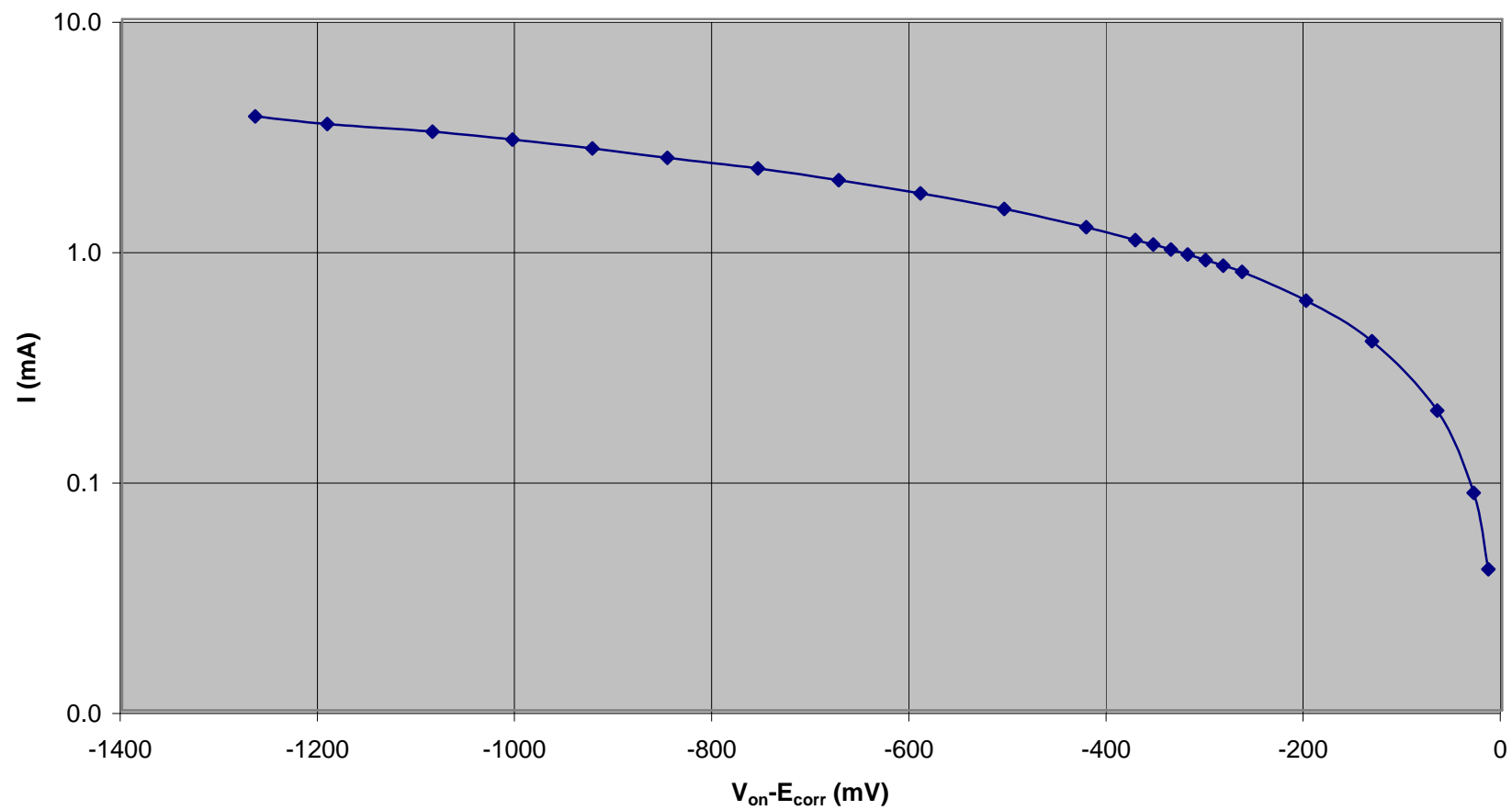
Bolt #9



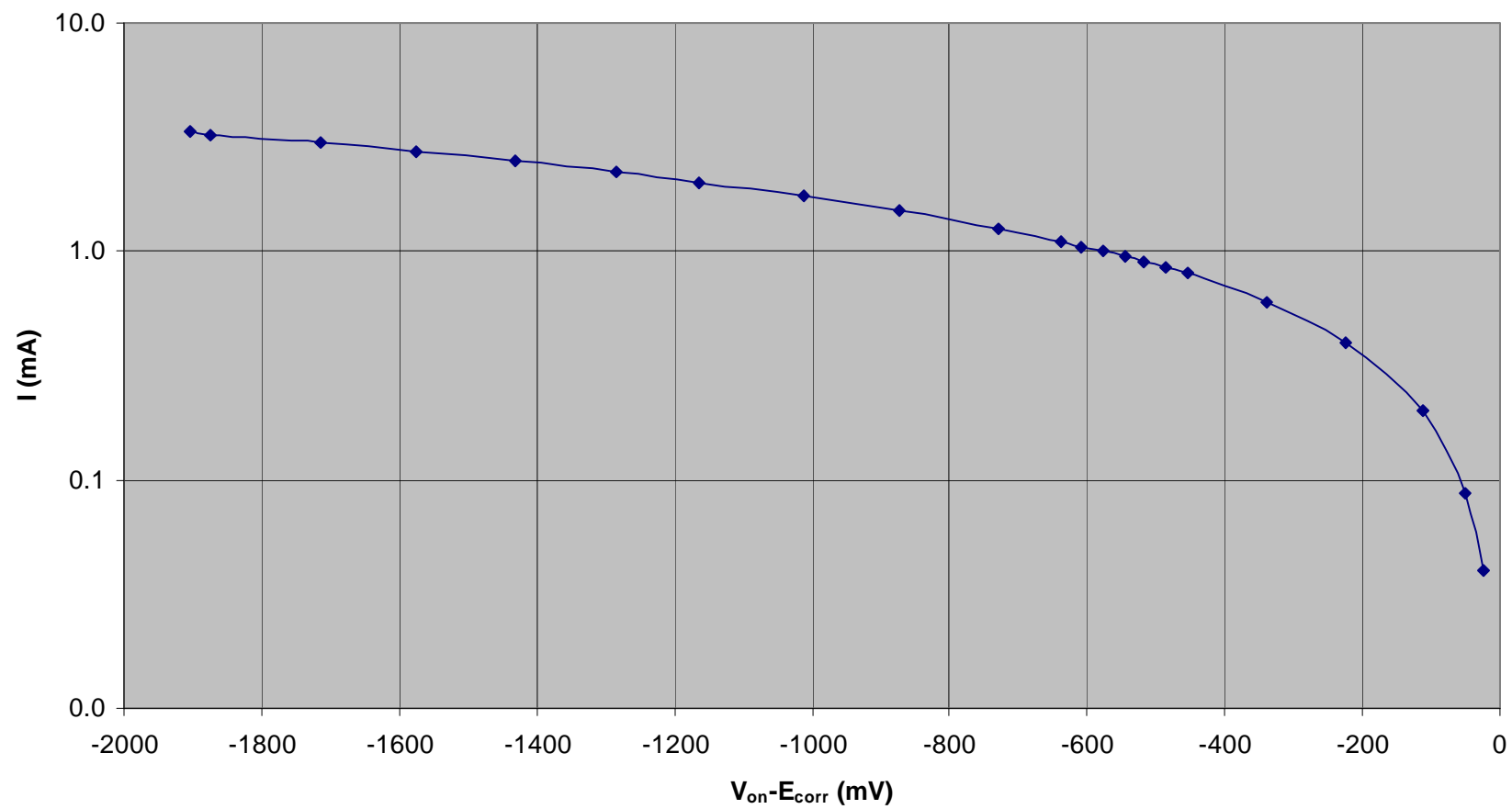
Bolt #10



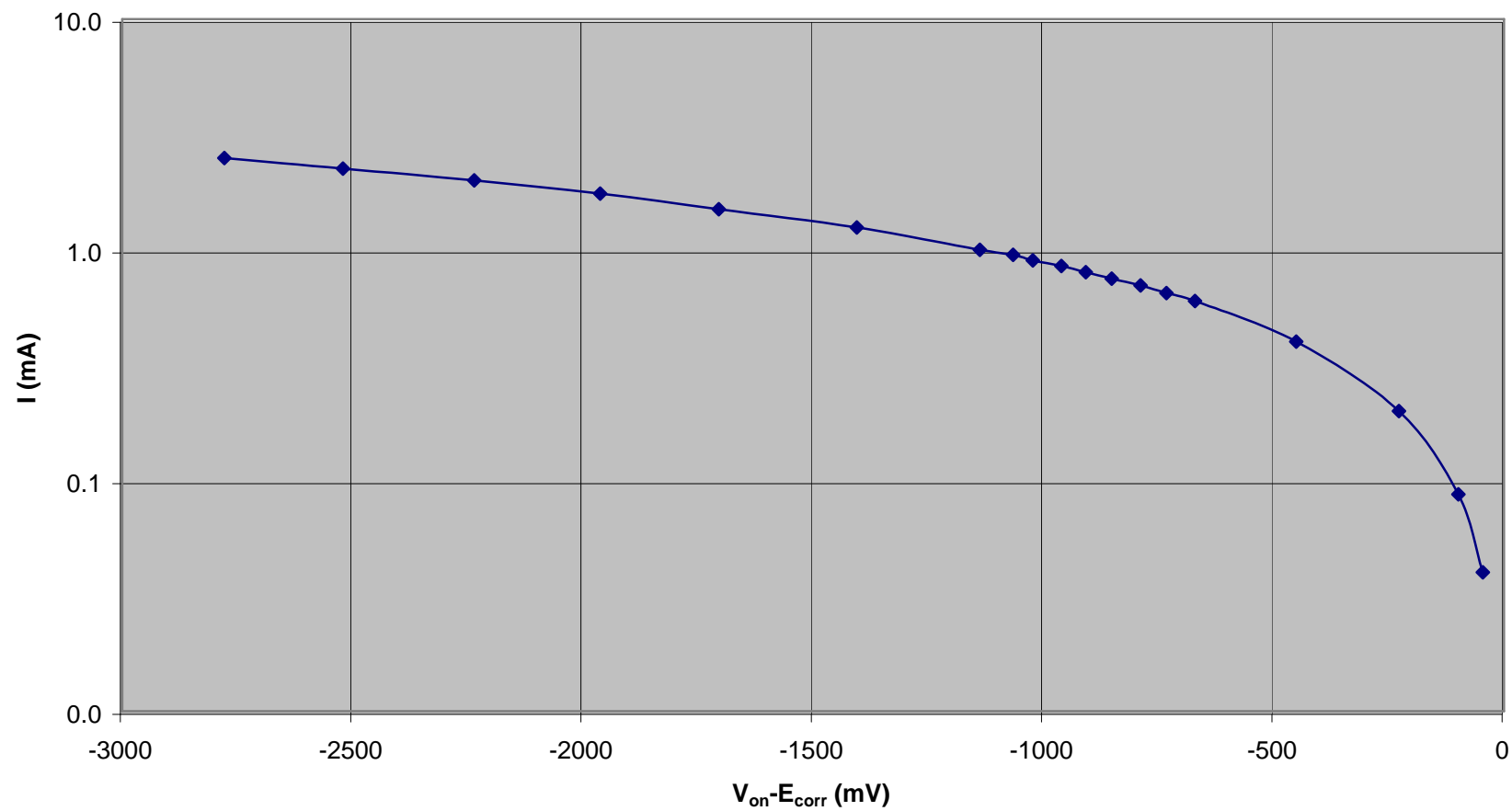
Bolt #11



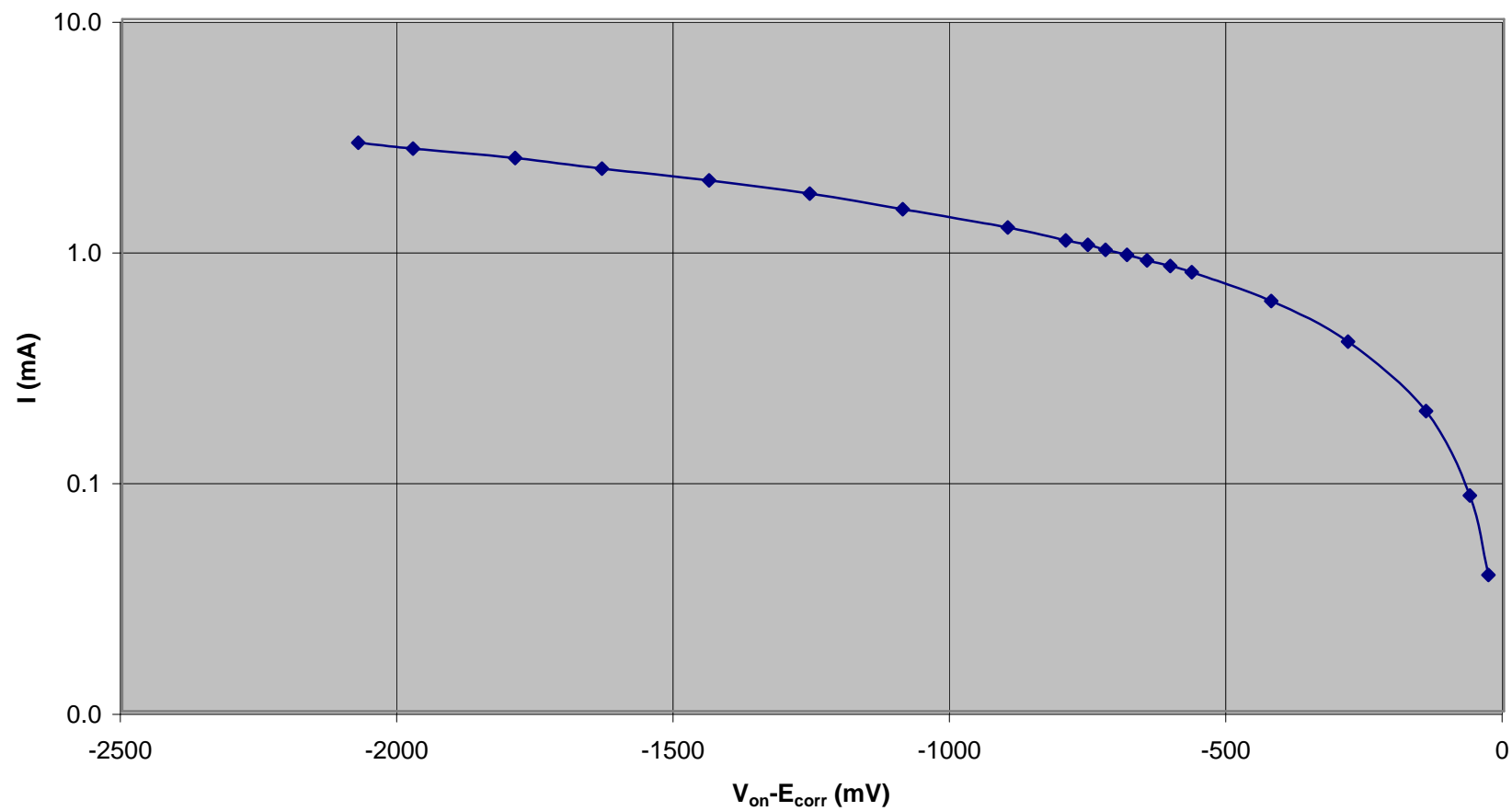
Bolt #12



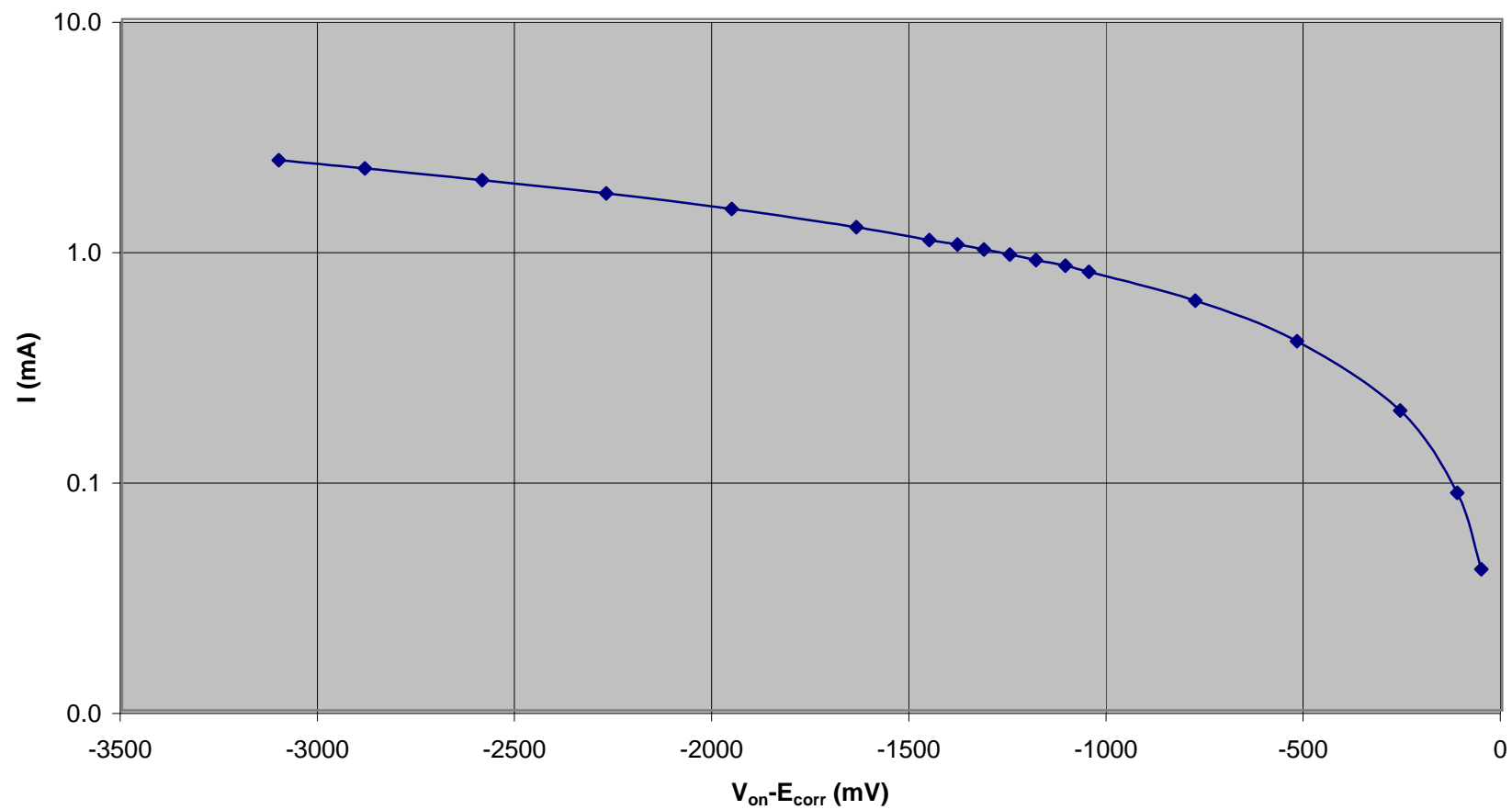
Bolt #13



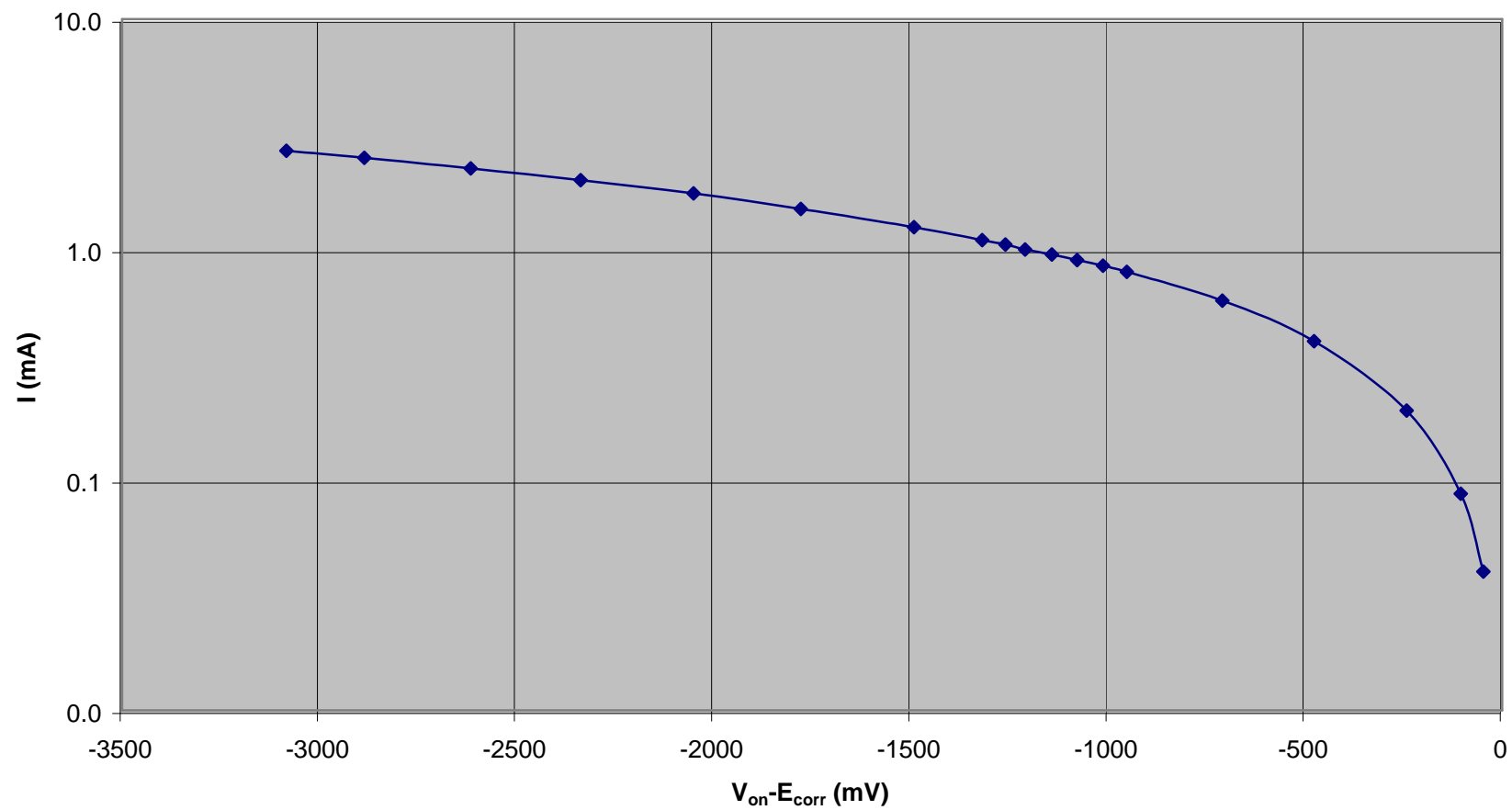
Bolt #14



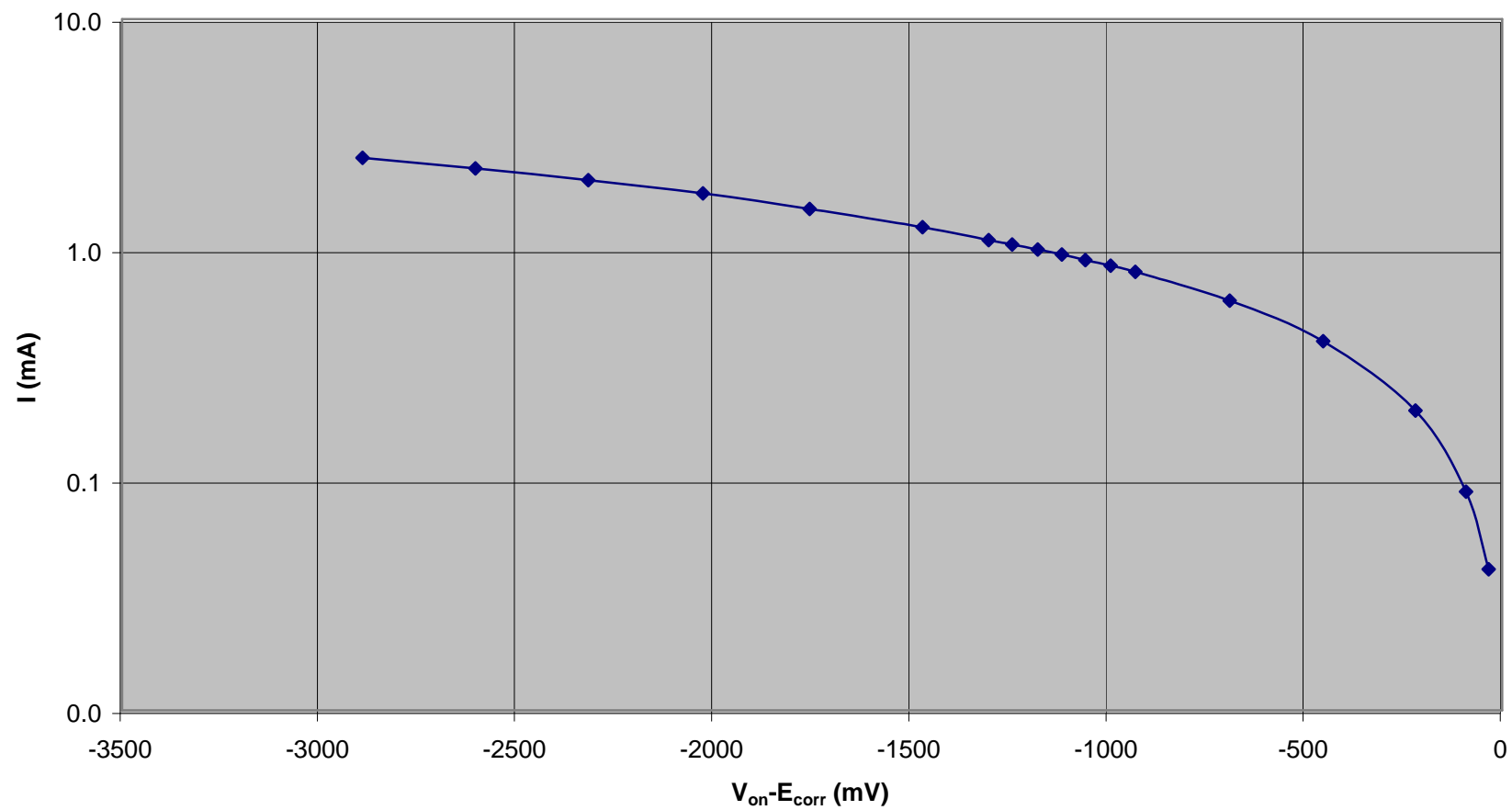
Bolt #15



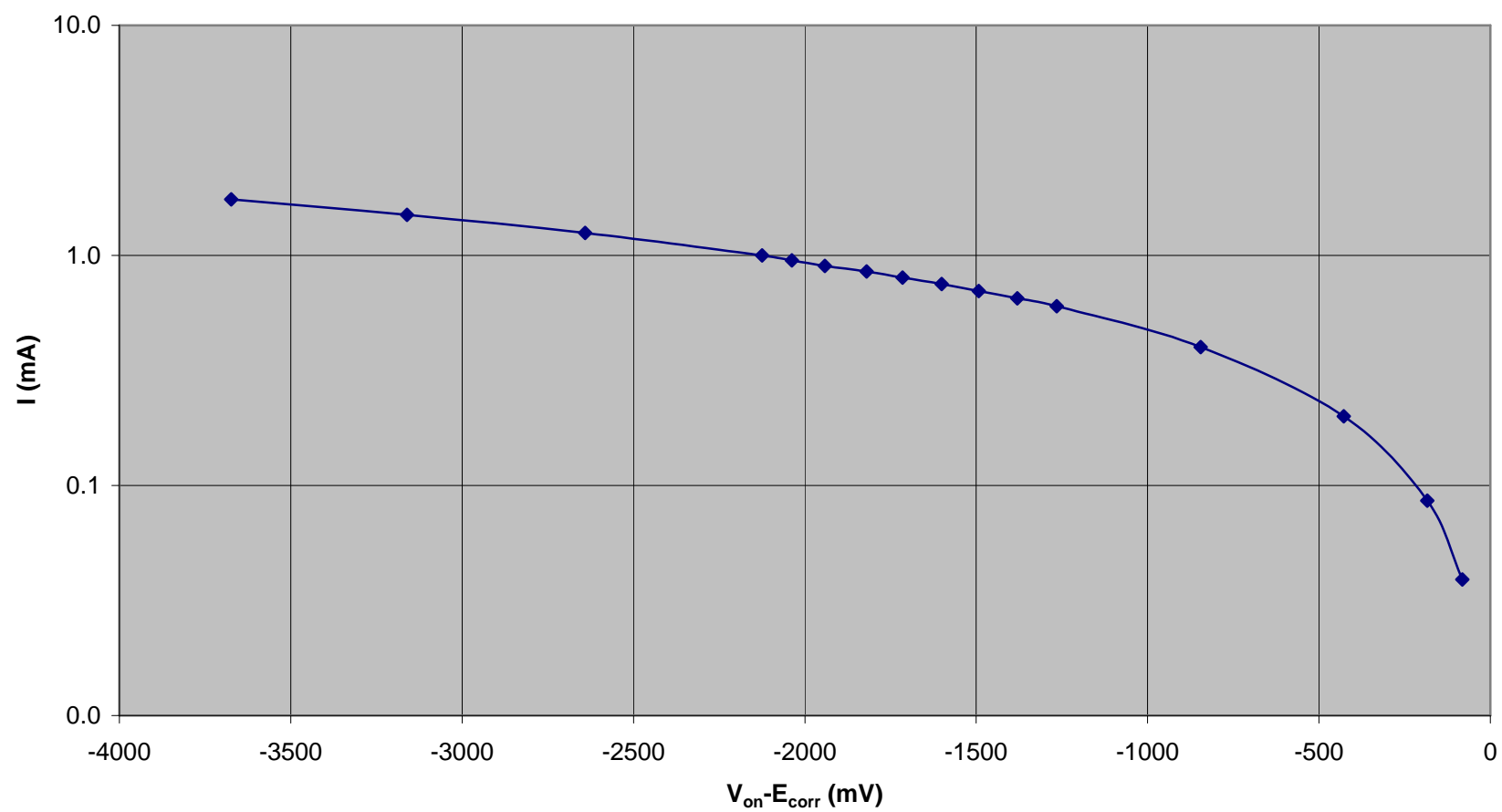
Bolt #16



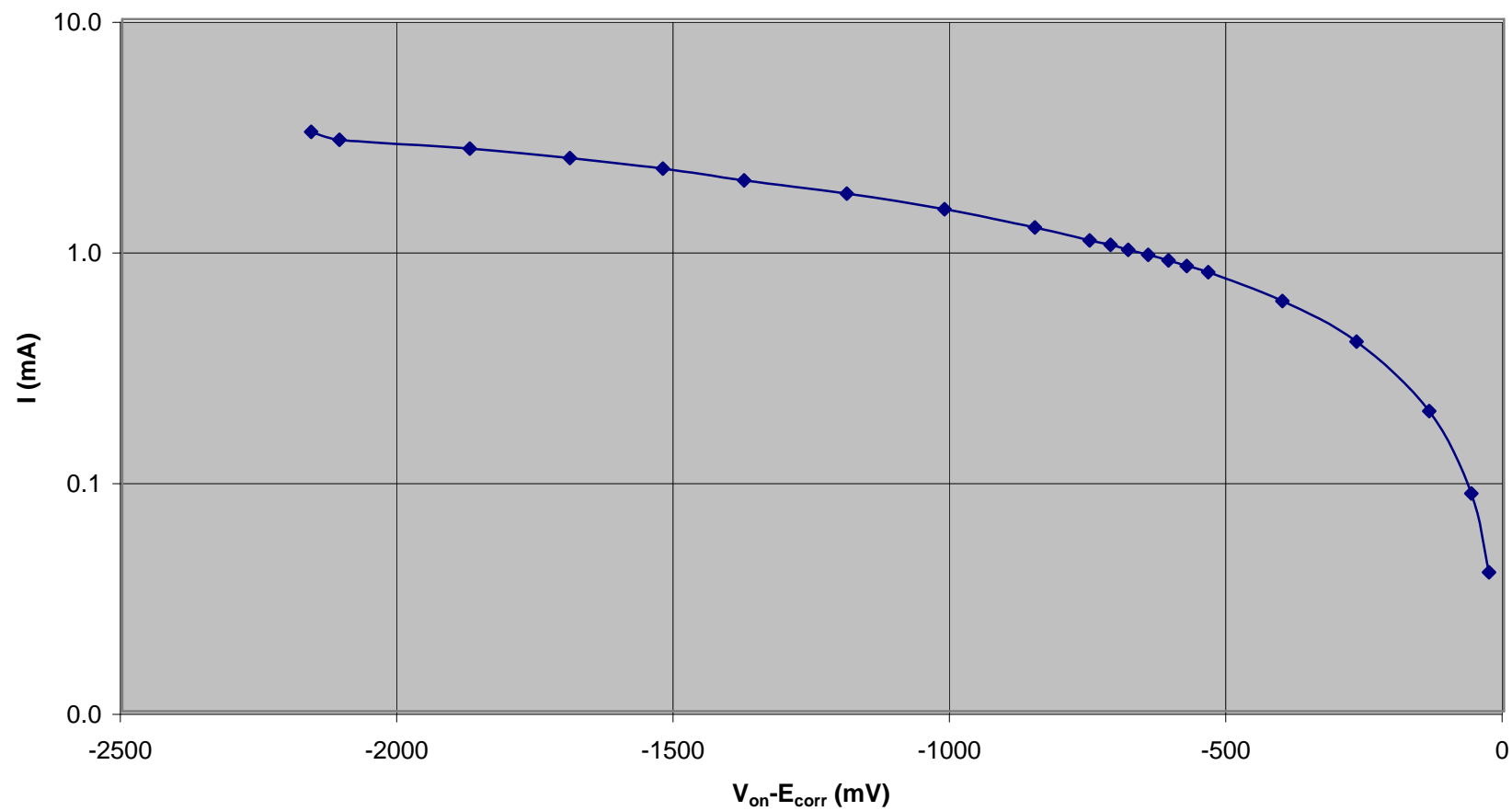
Bolt #17



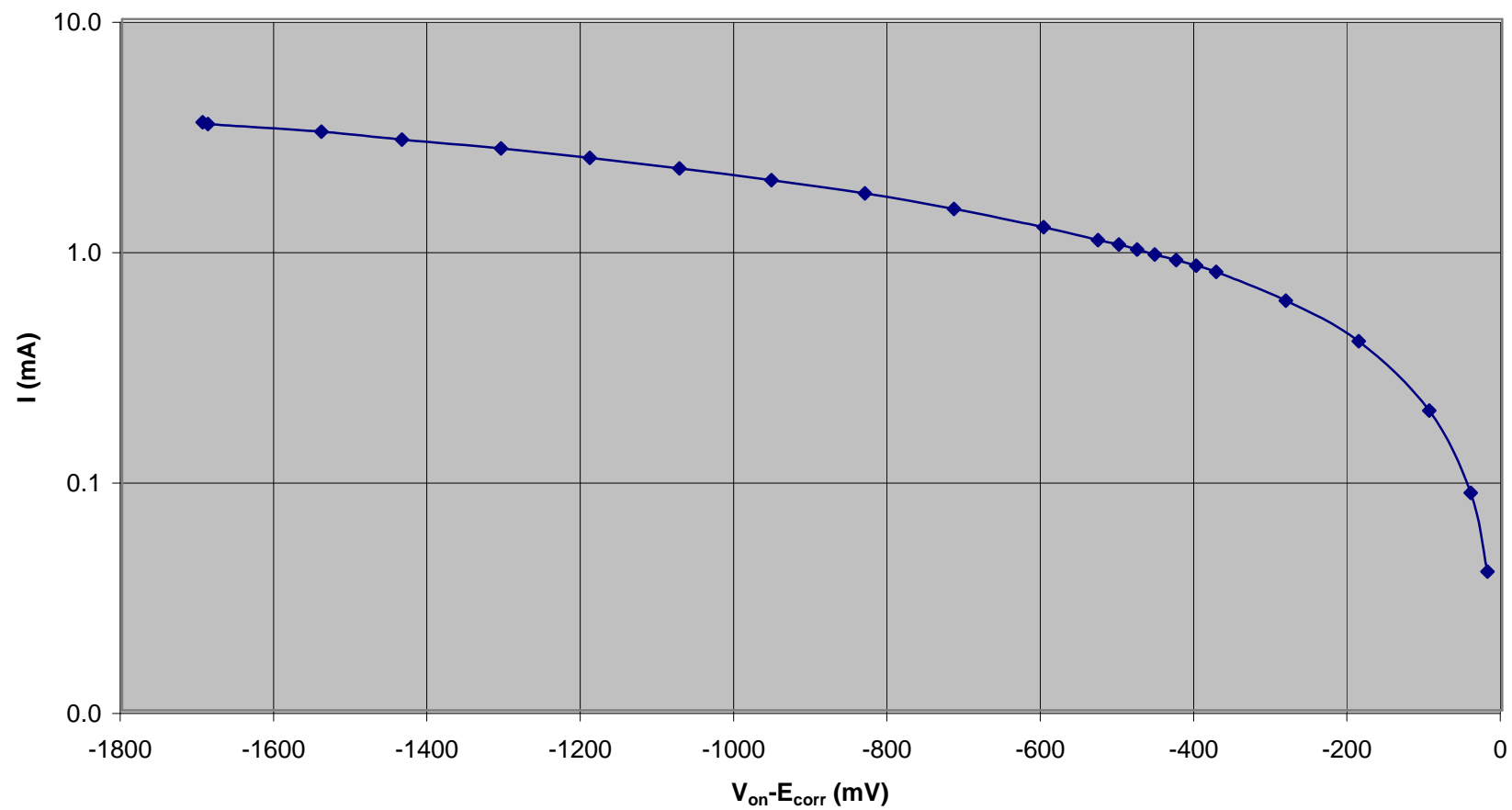
Bolt #18



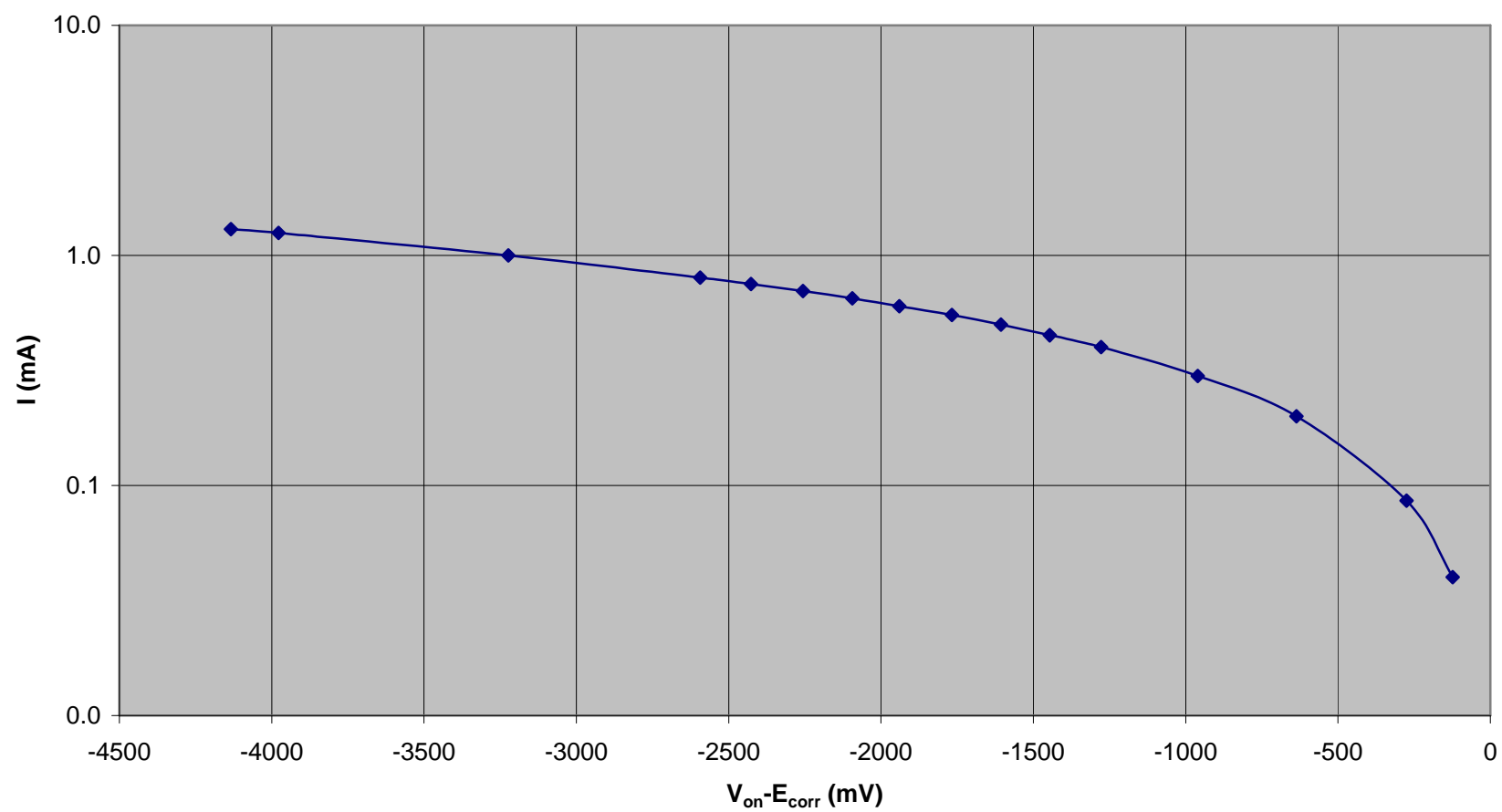
Bolt #19



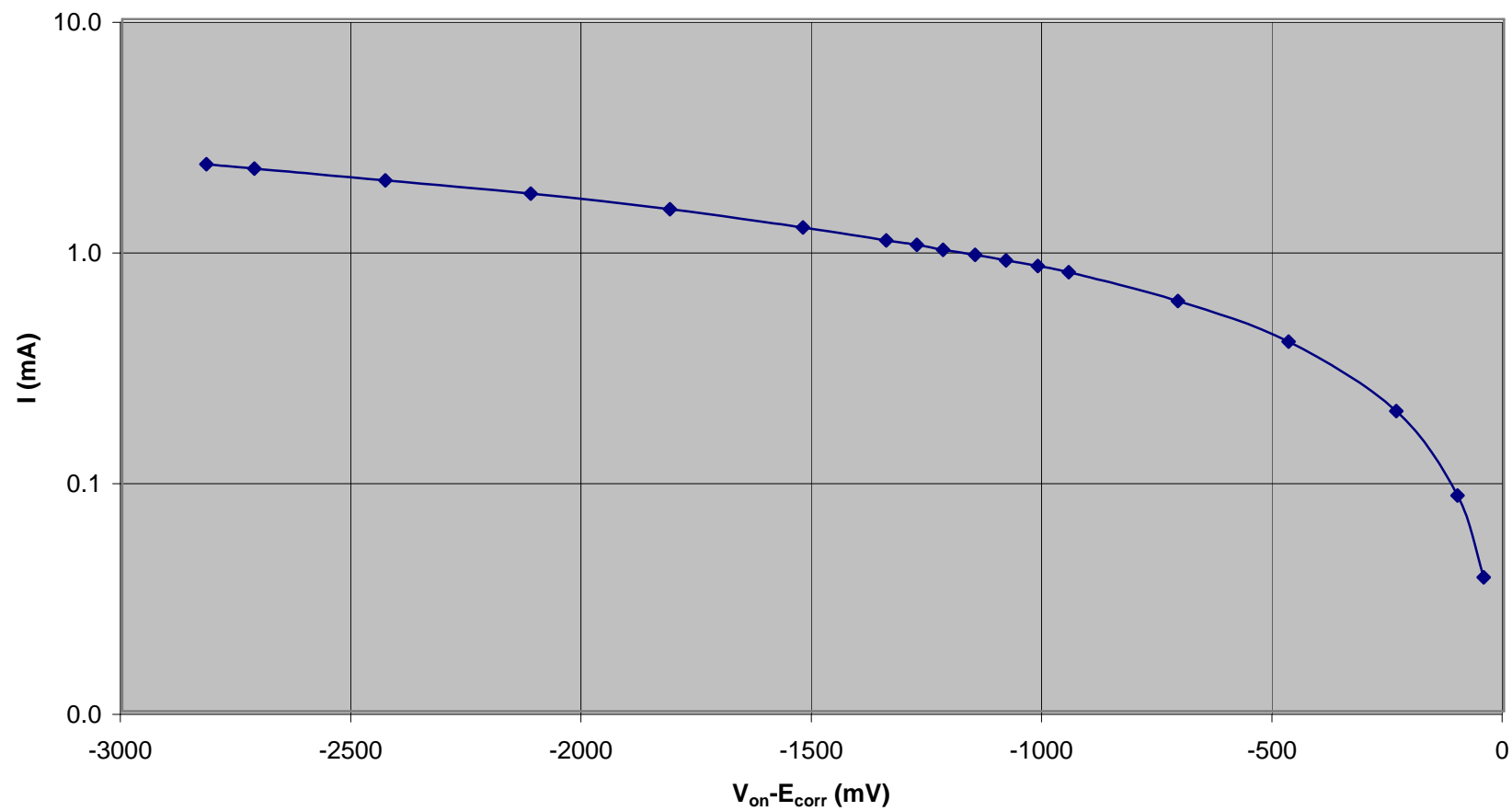
Bolt #20



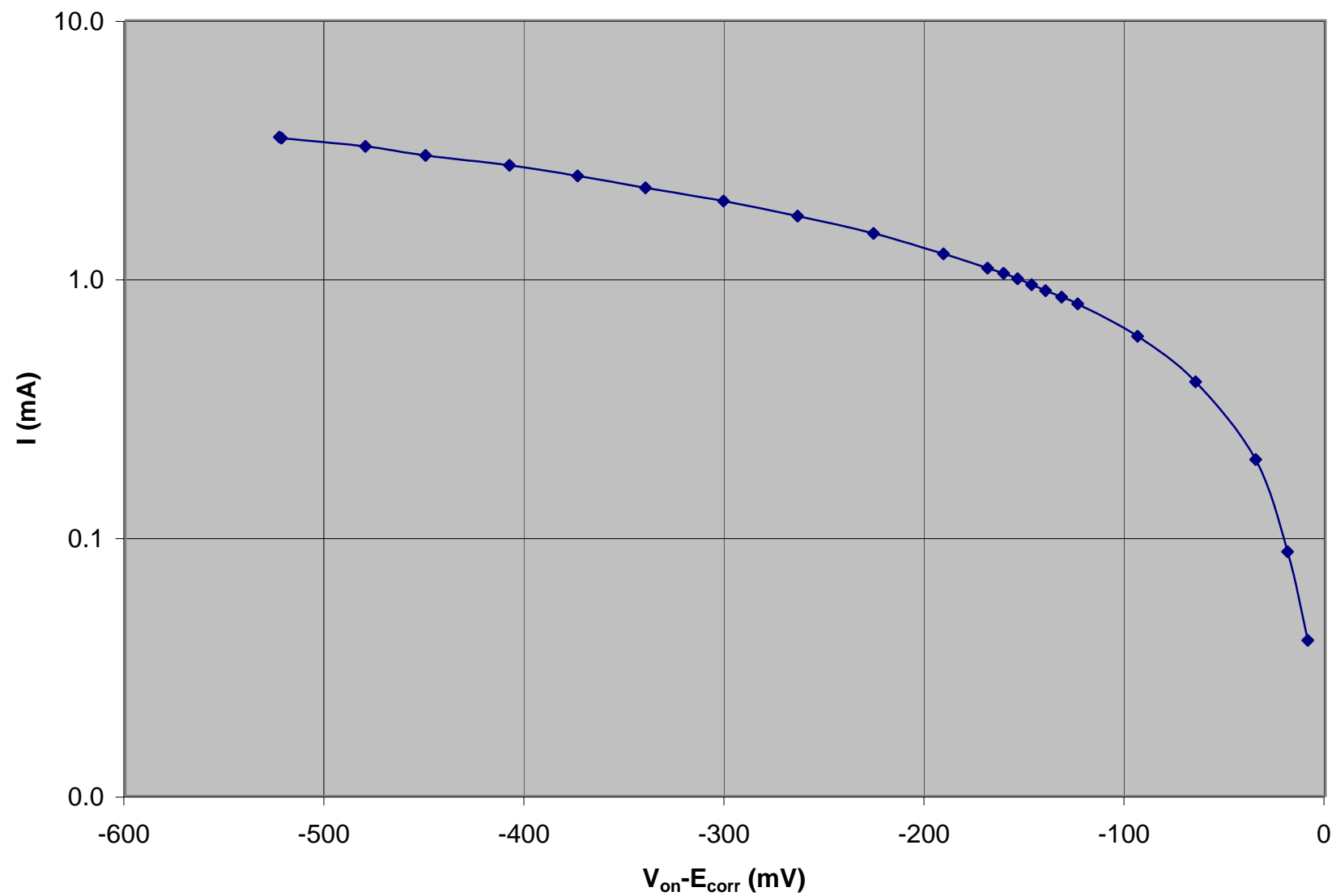
Bolt #21



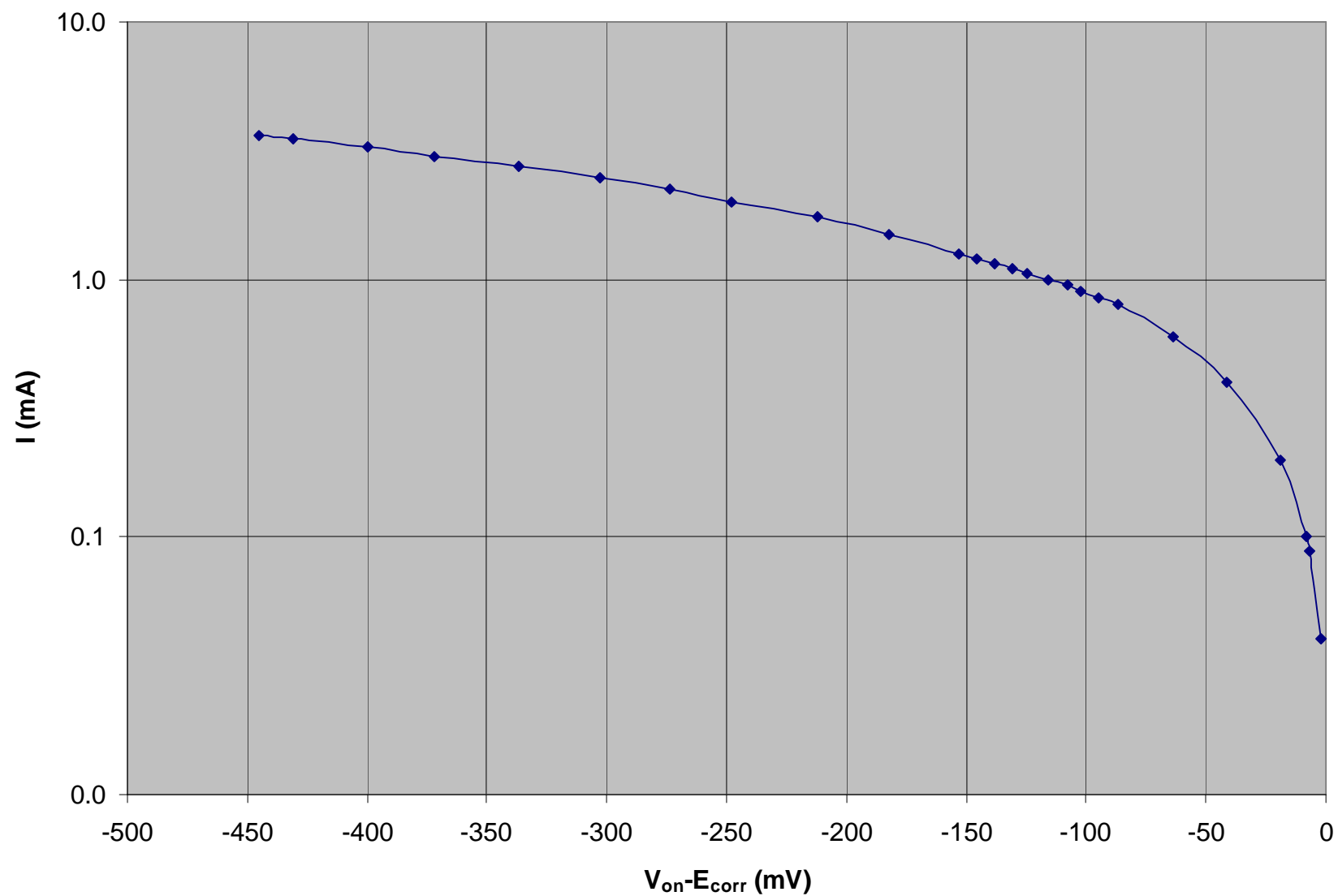
Bolt #22



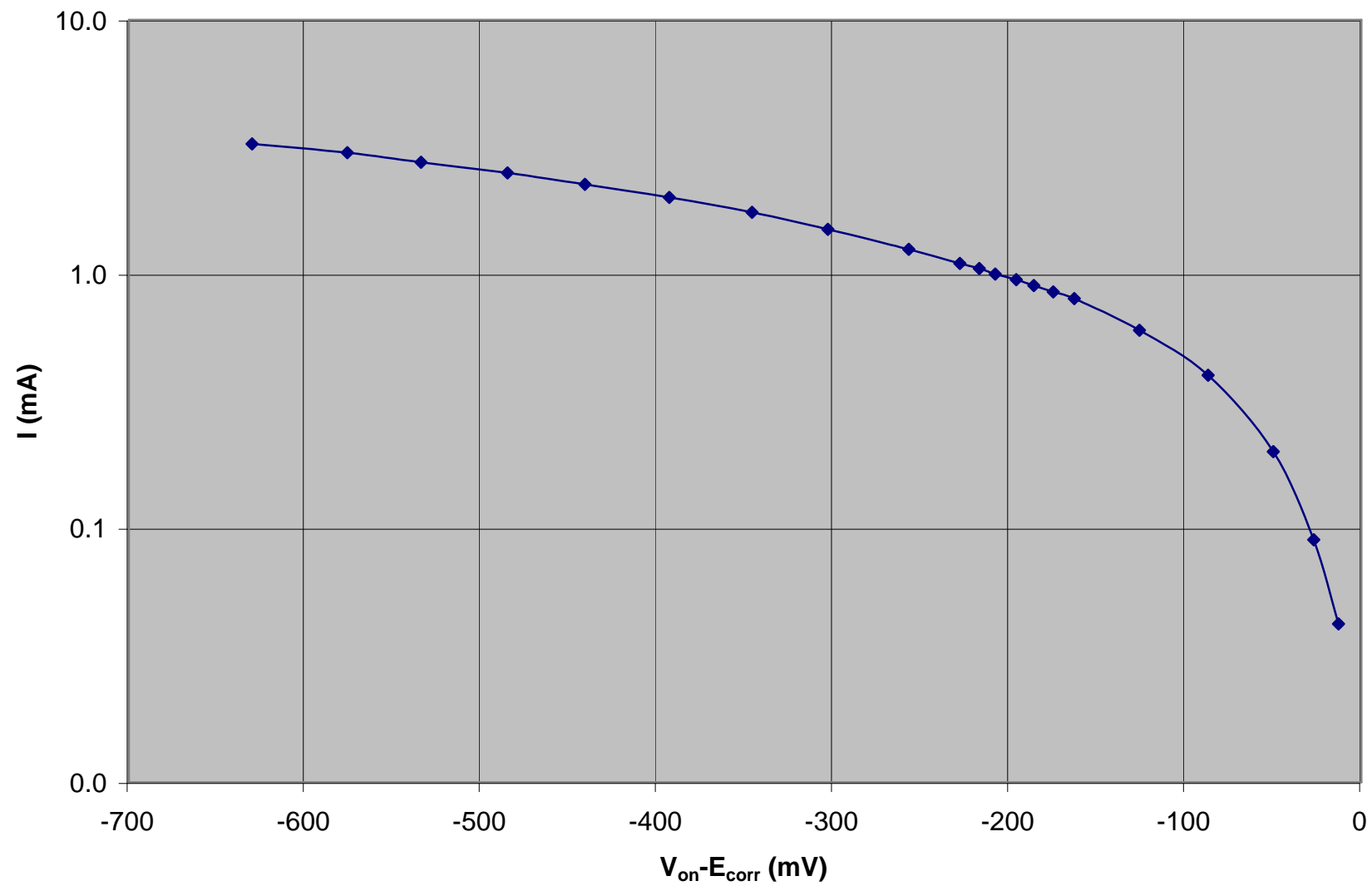
Tendon 1-1



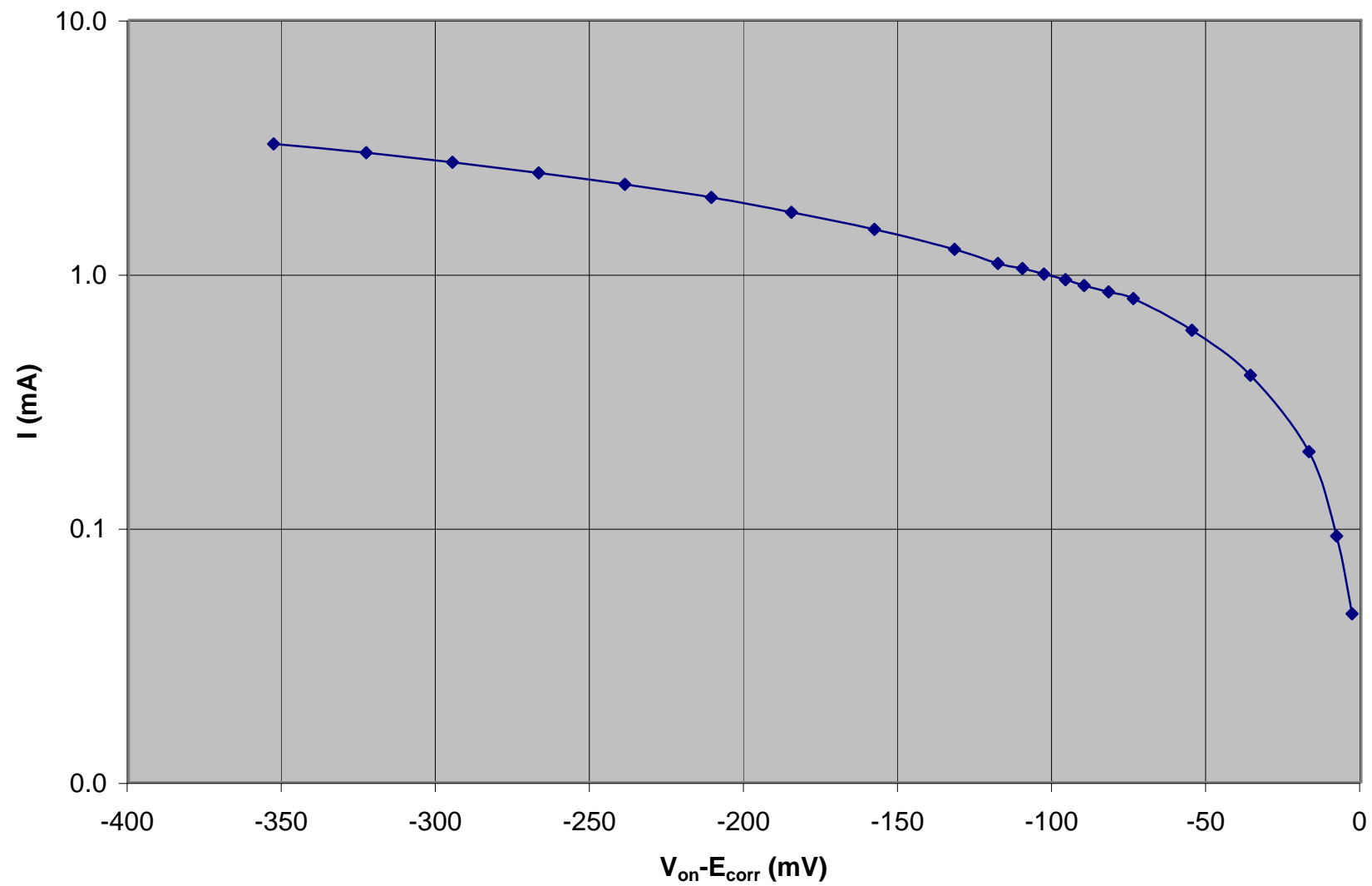
Tendon 1-2



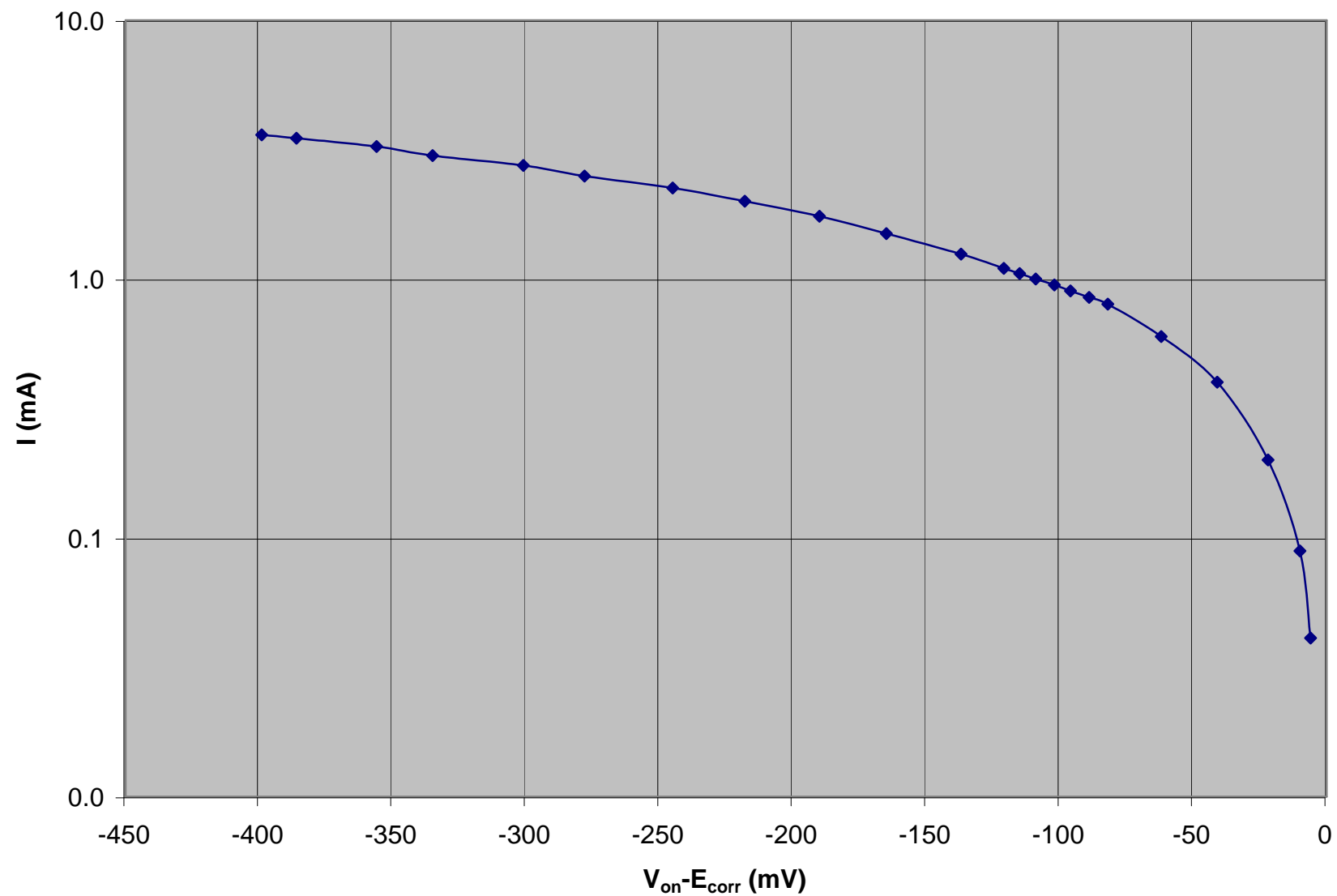
Tendon 1-3



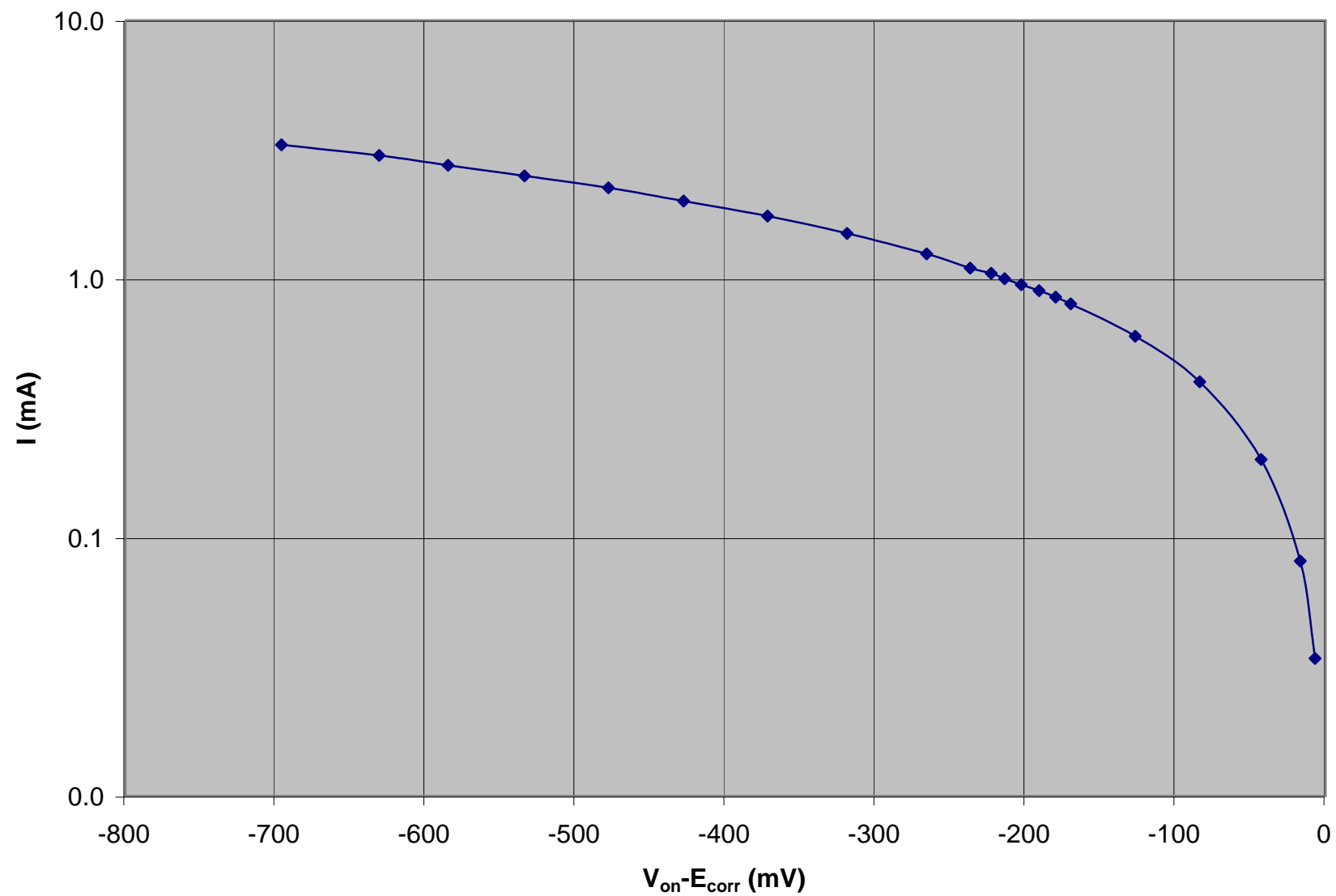
Tendon 1-4



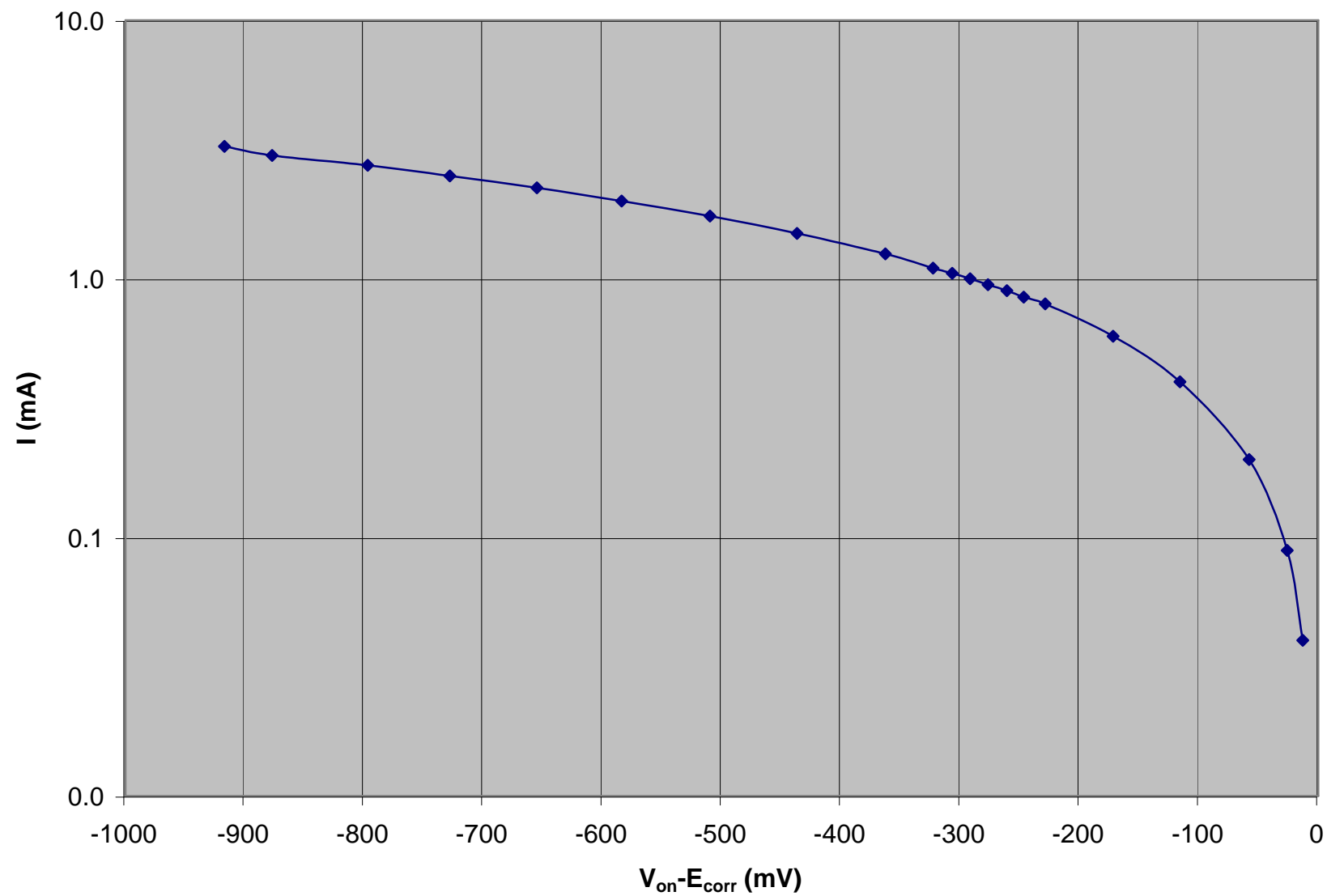
Tendon 2-1



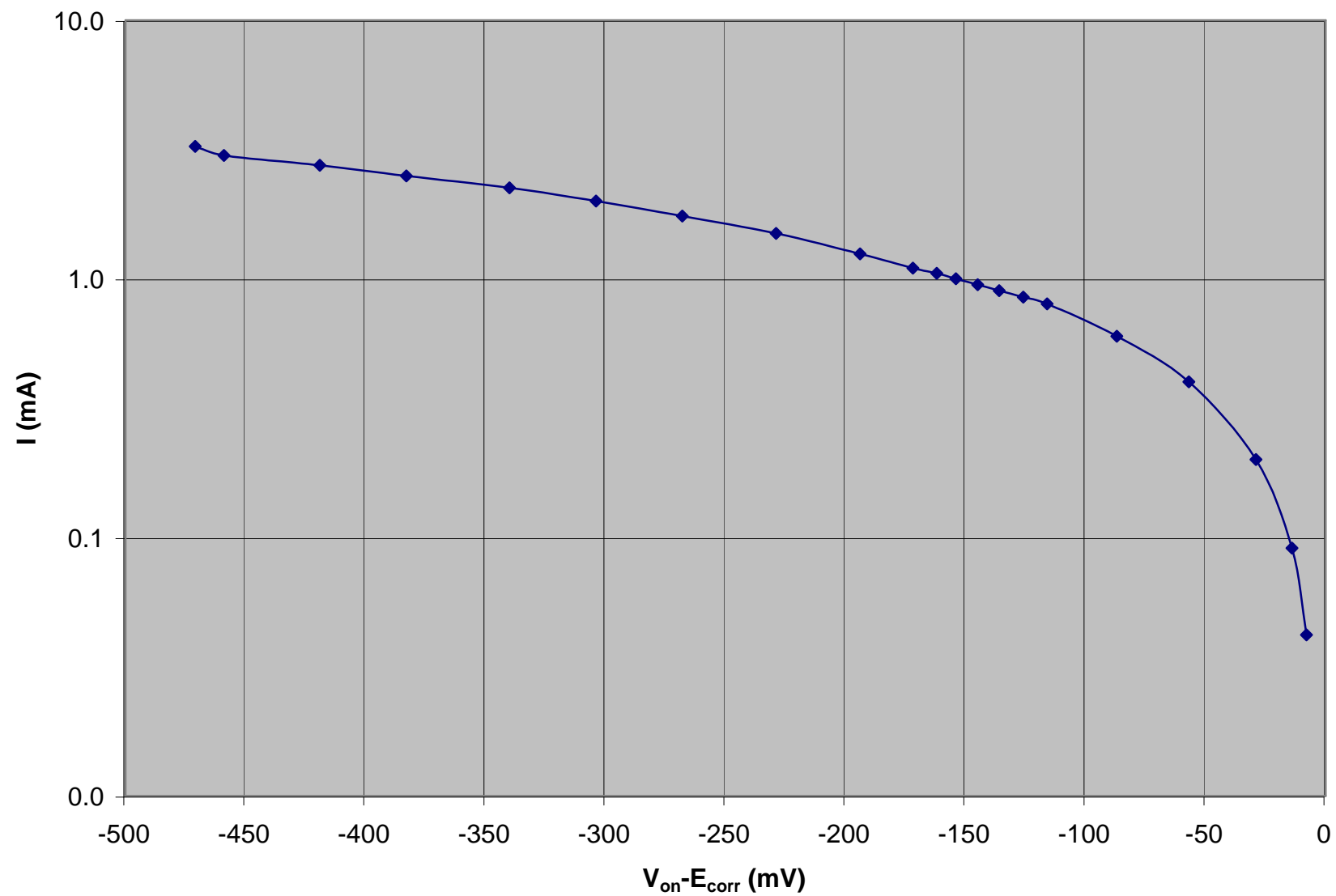
Tendon 2-2



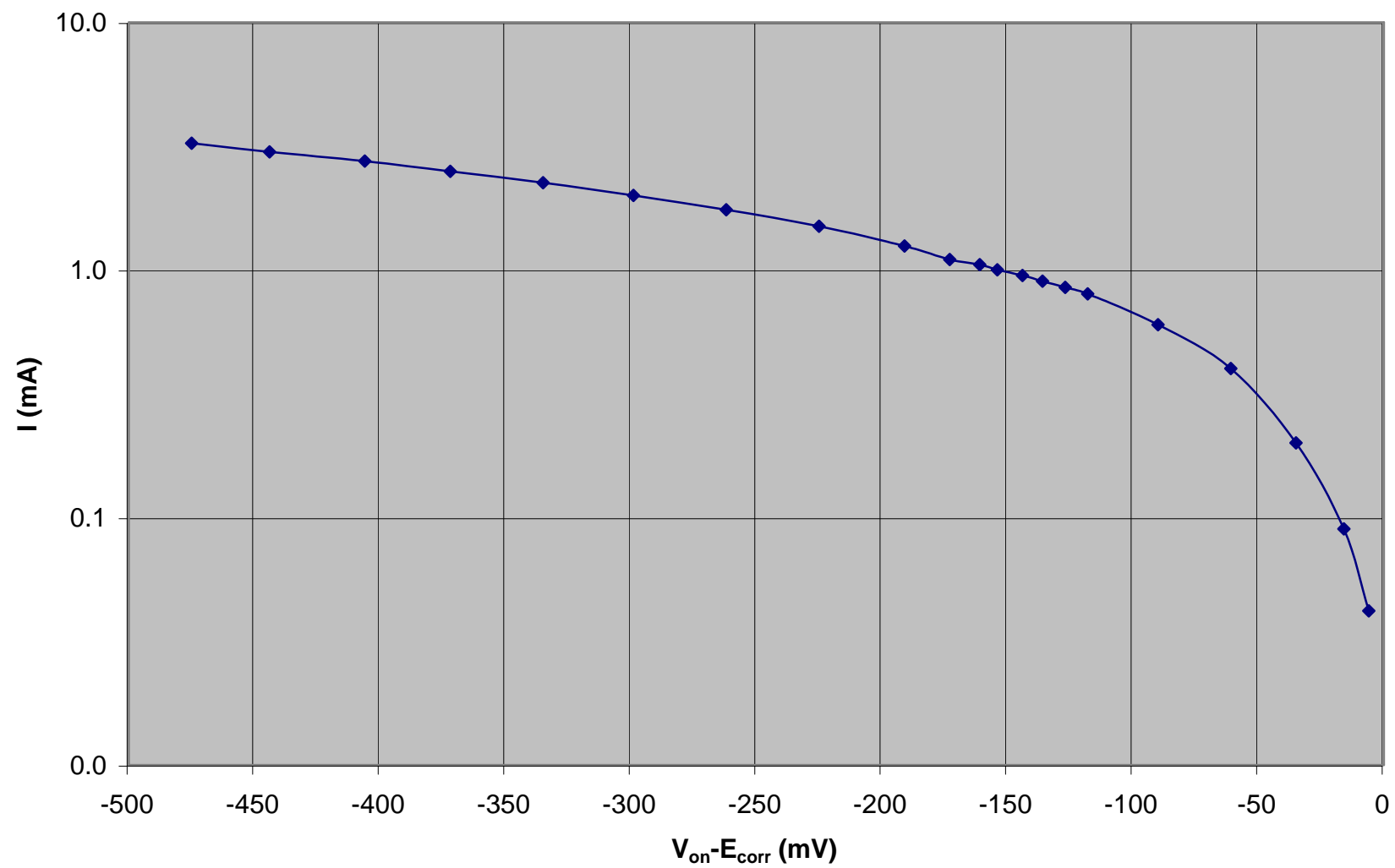
Tendon 2-3



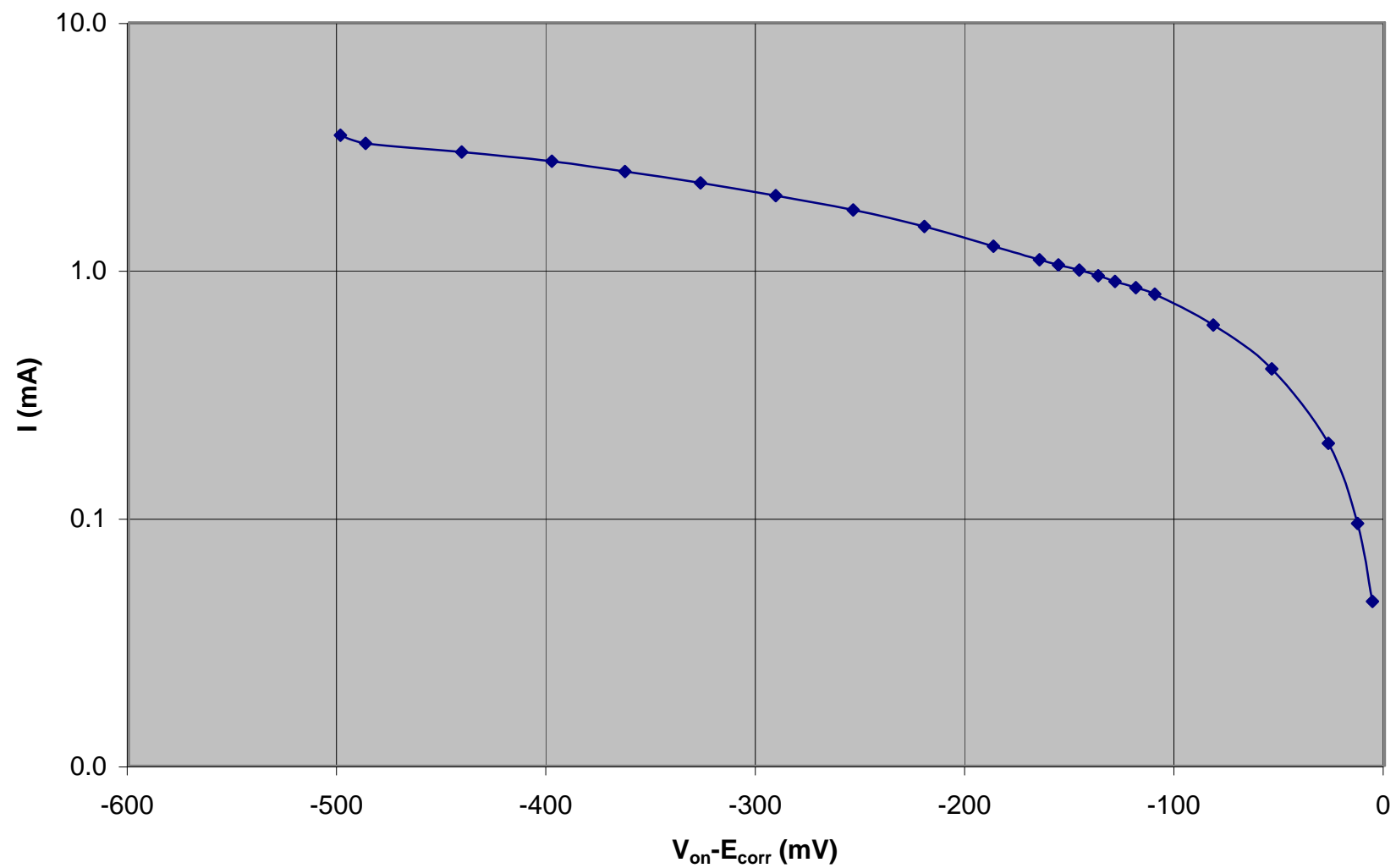
Tendon 2-4



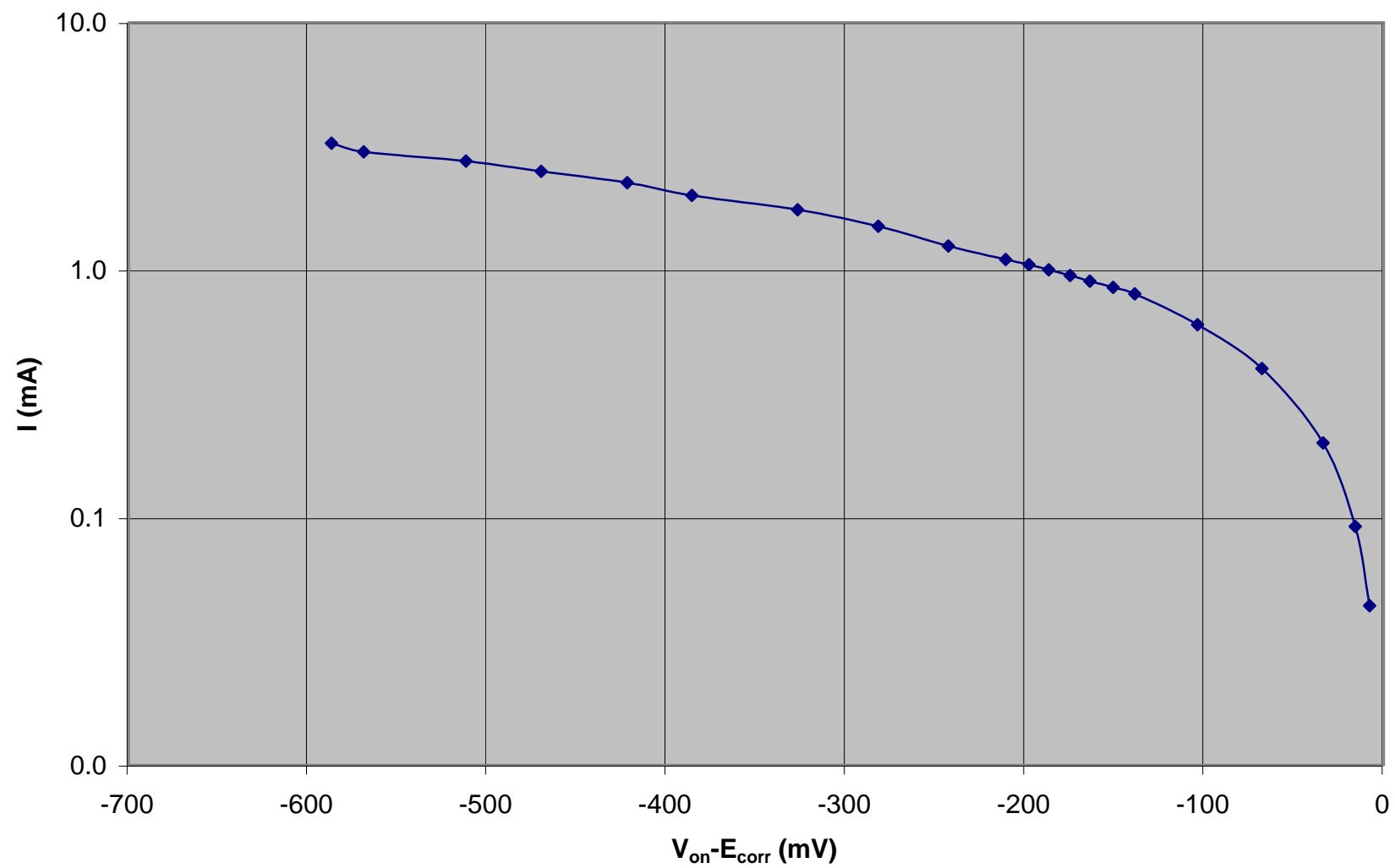
Tendon 3-1



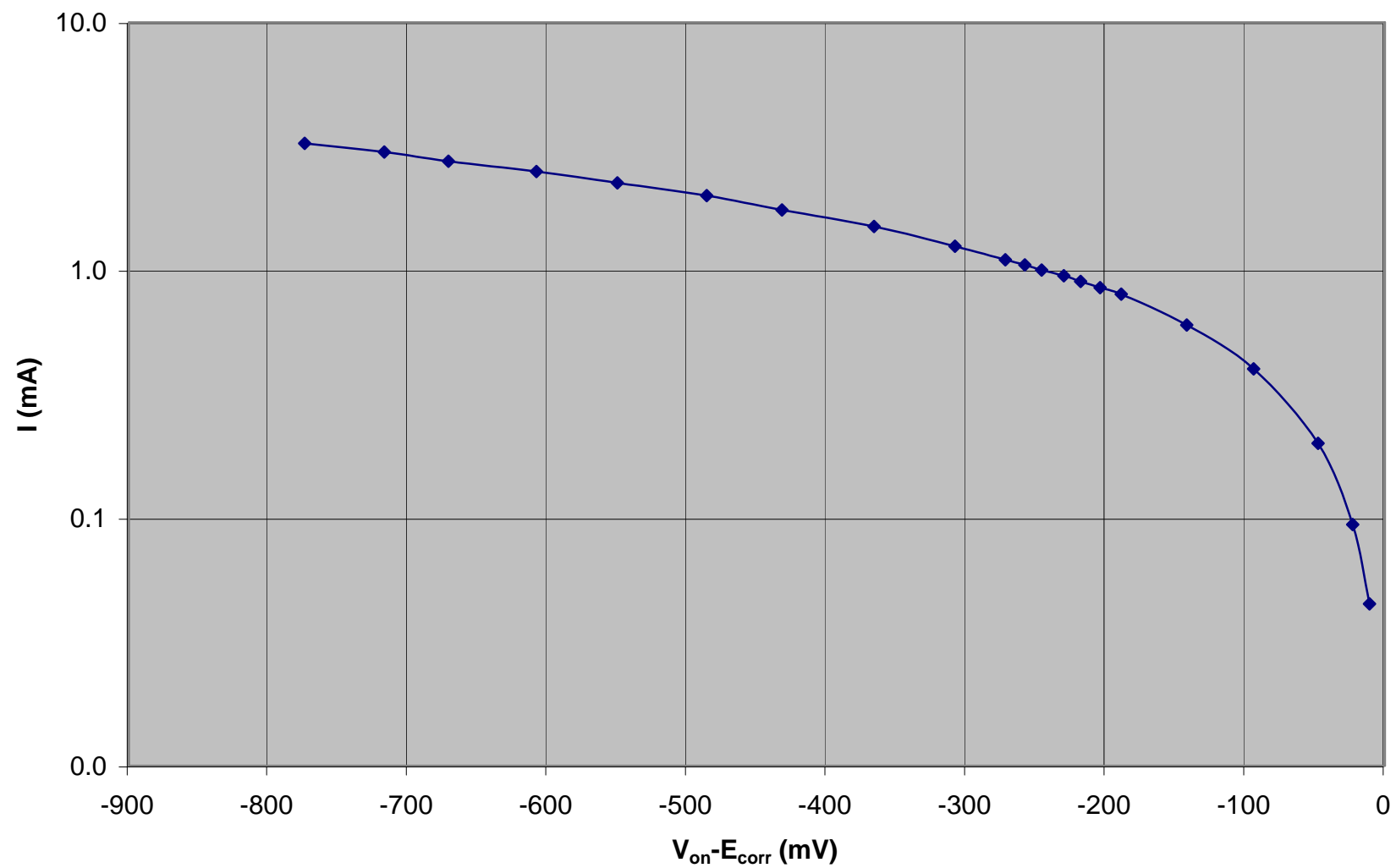
Tendon 3-2



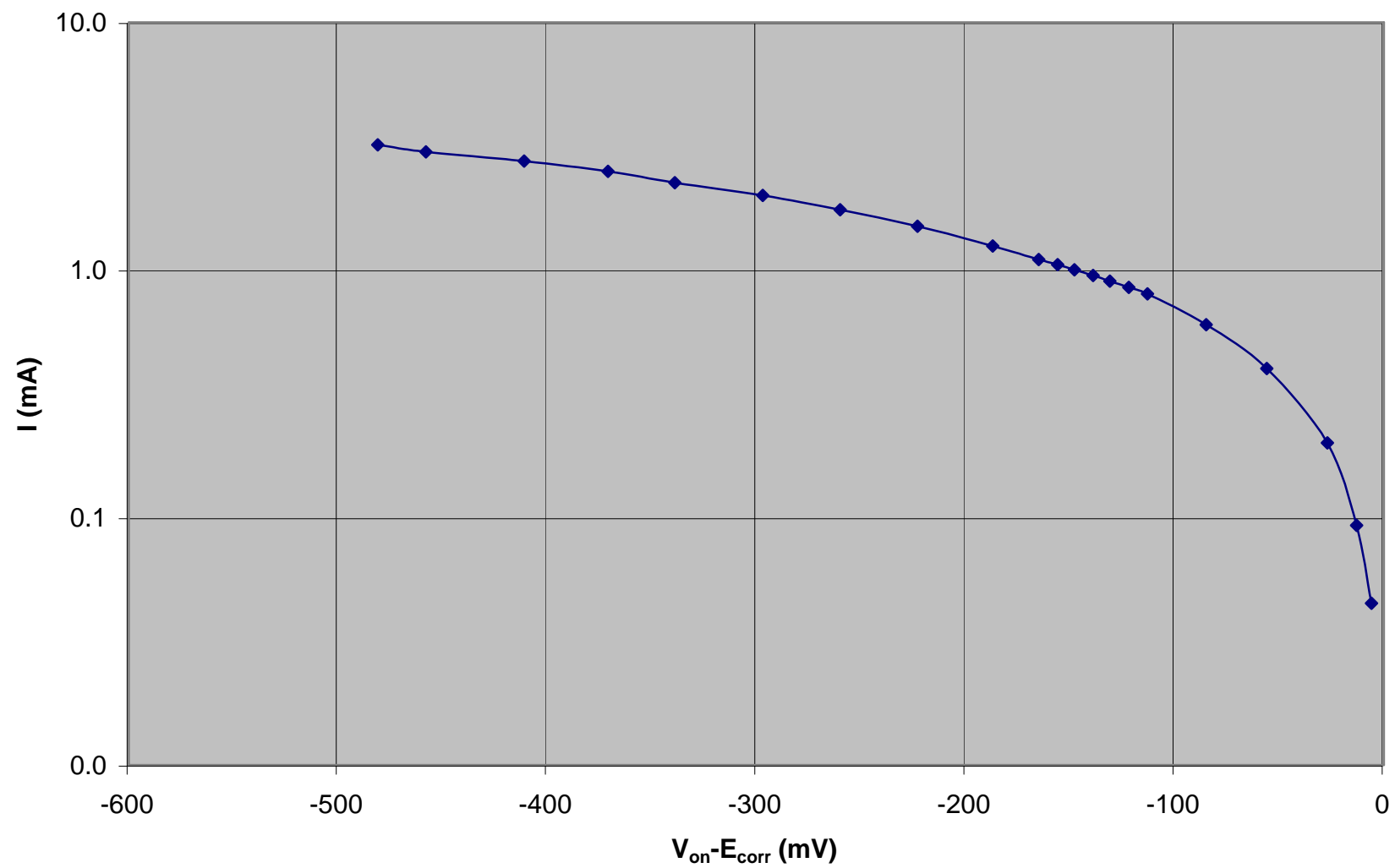
Tendon 3-3



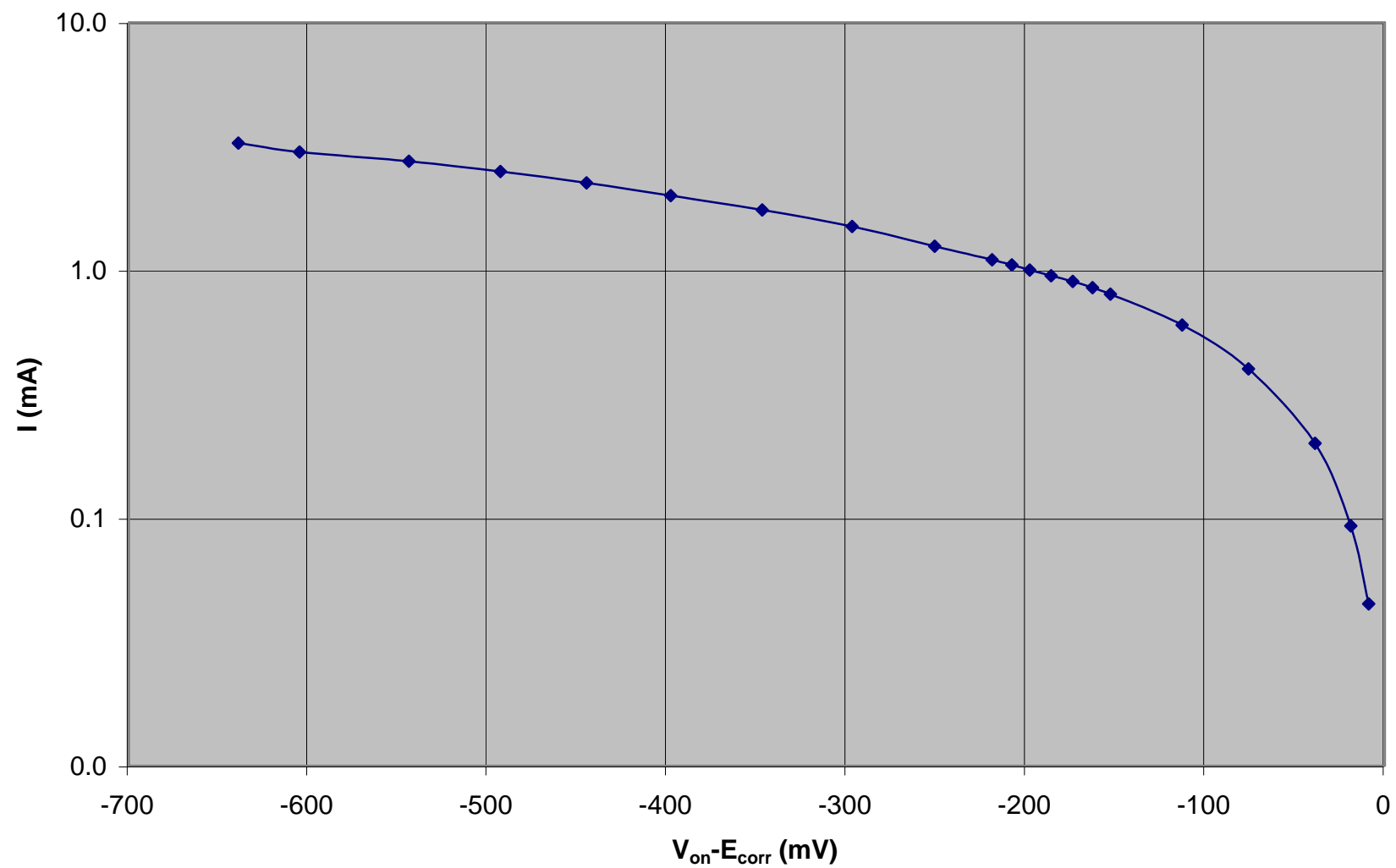
Tendon 3-4



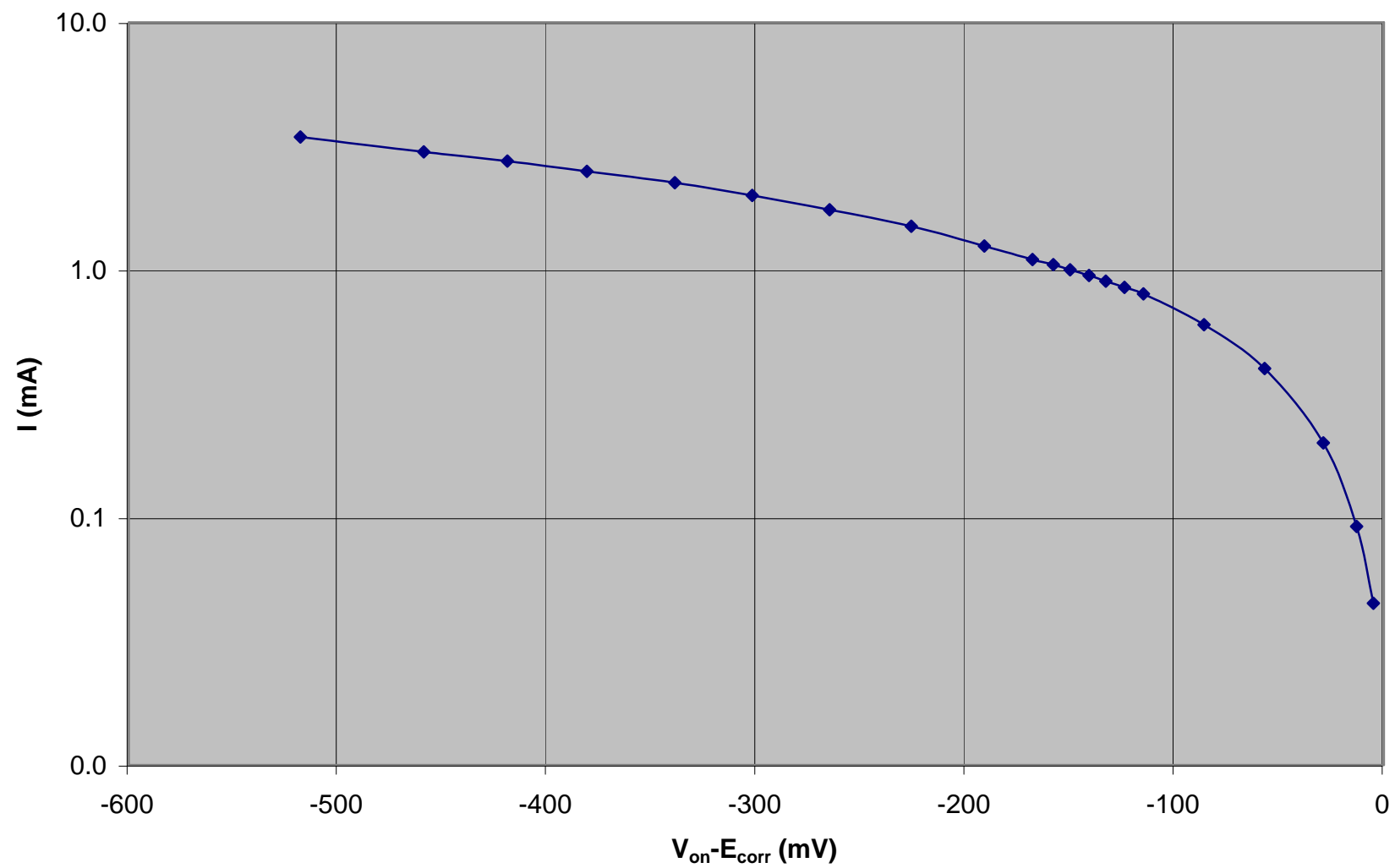
Tendon 4-1



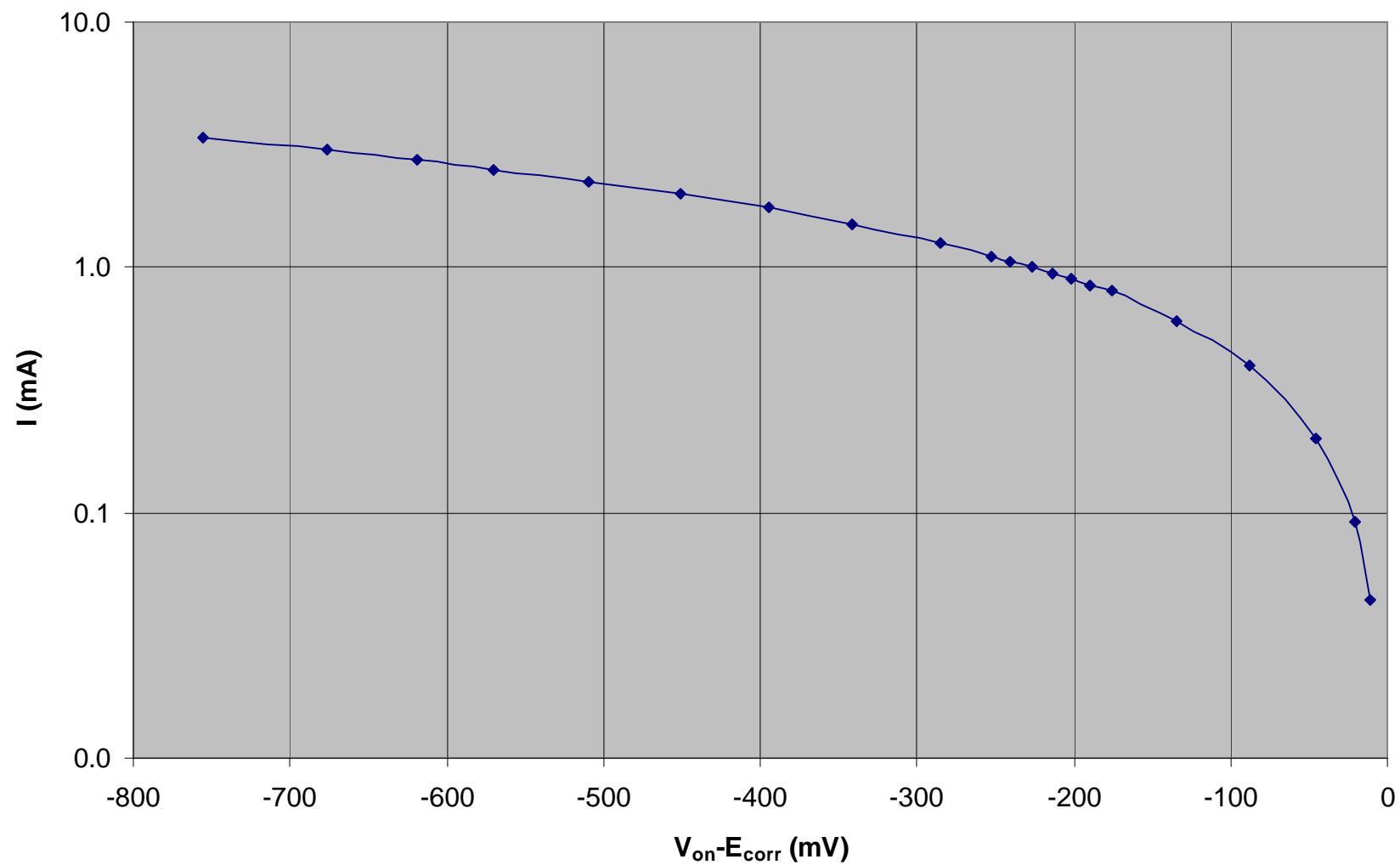
Tendon 4-2



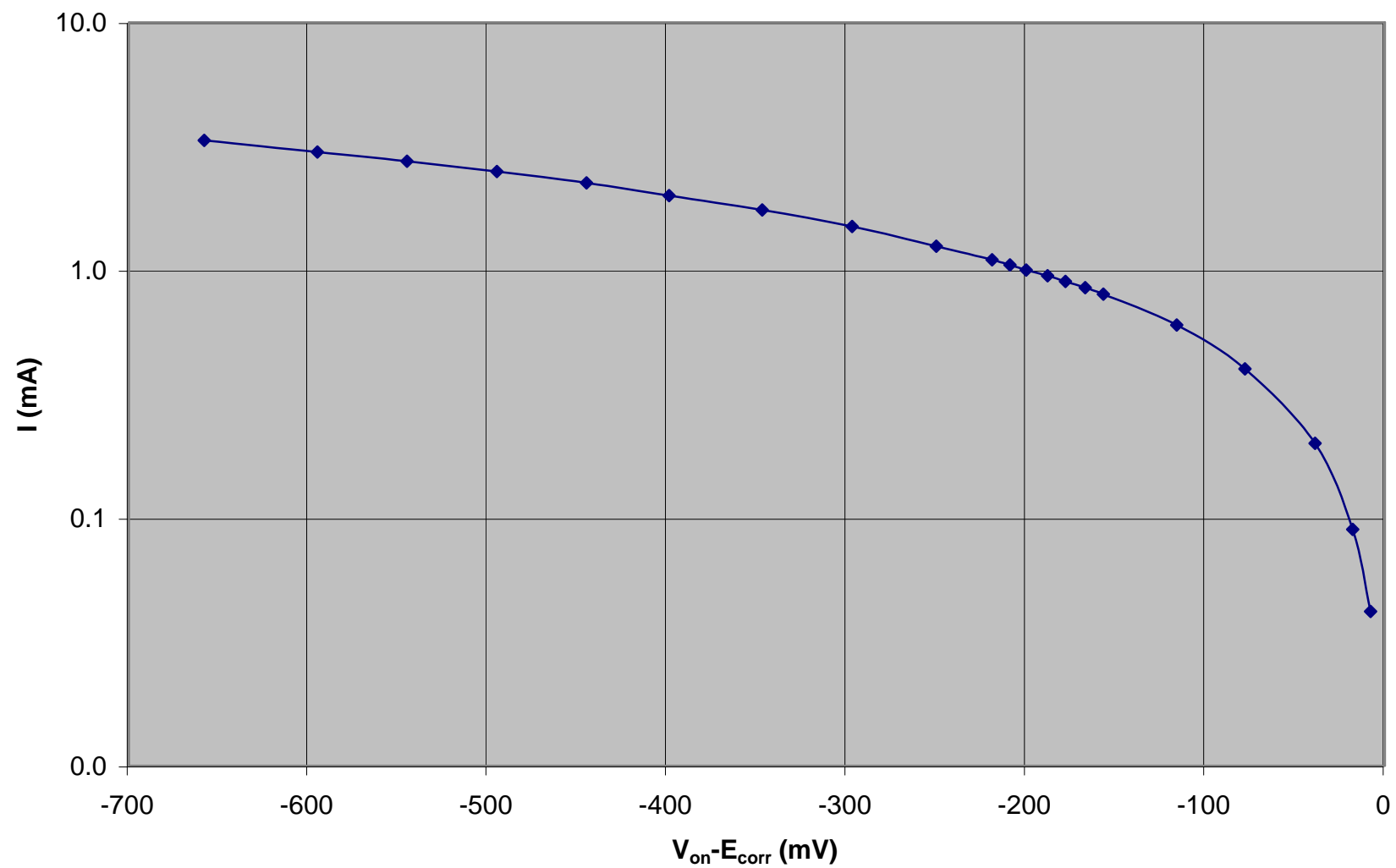
Tendon 4-3



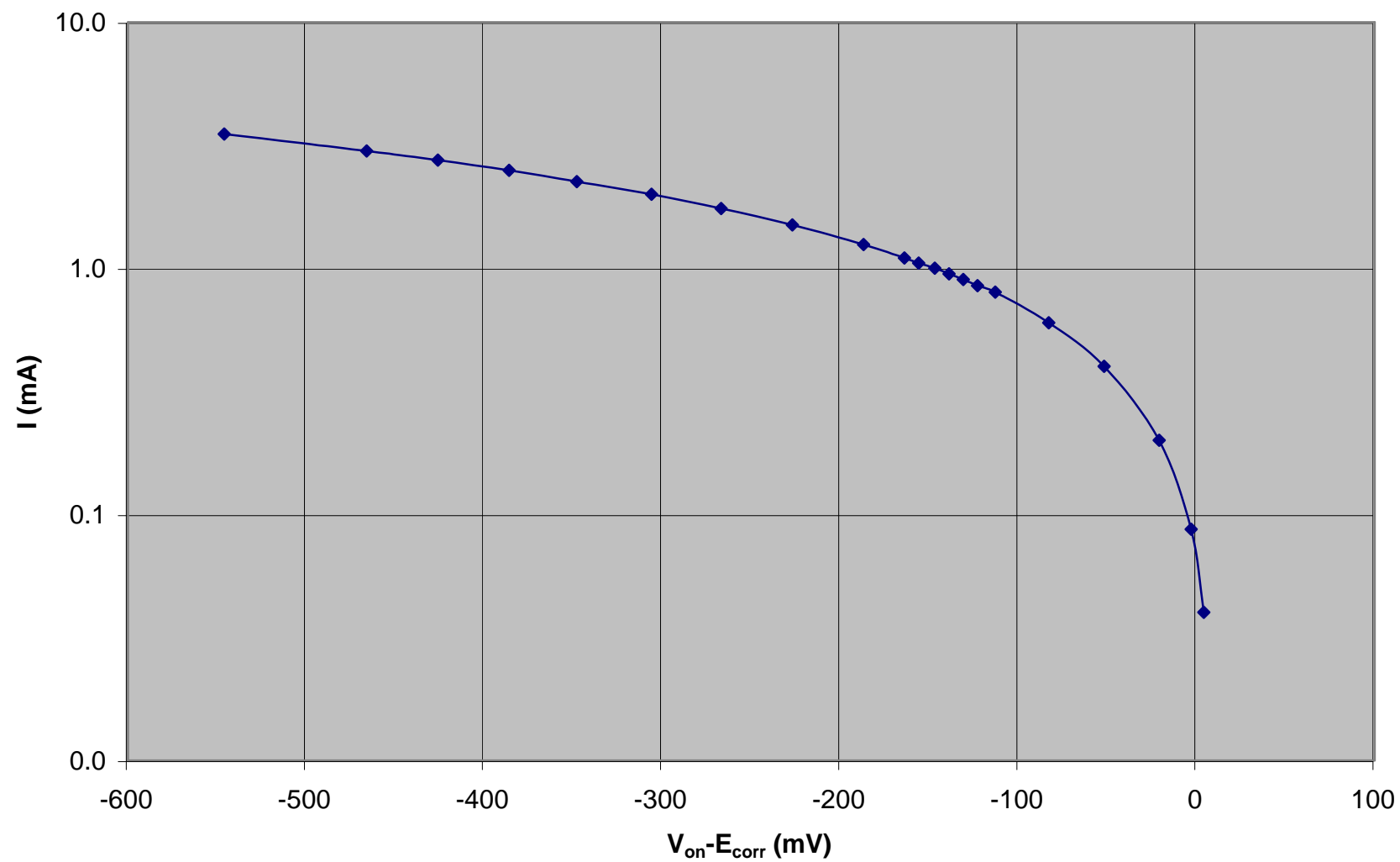
Tendon 4-4



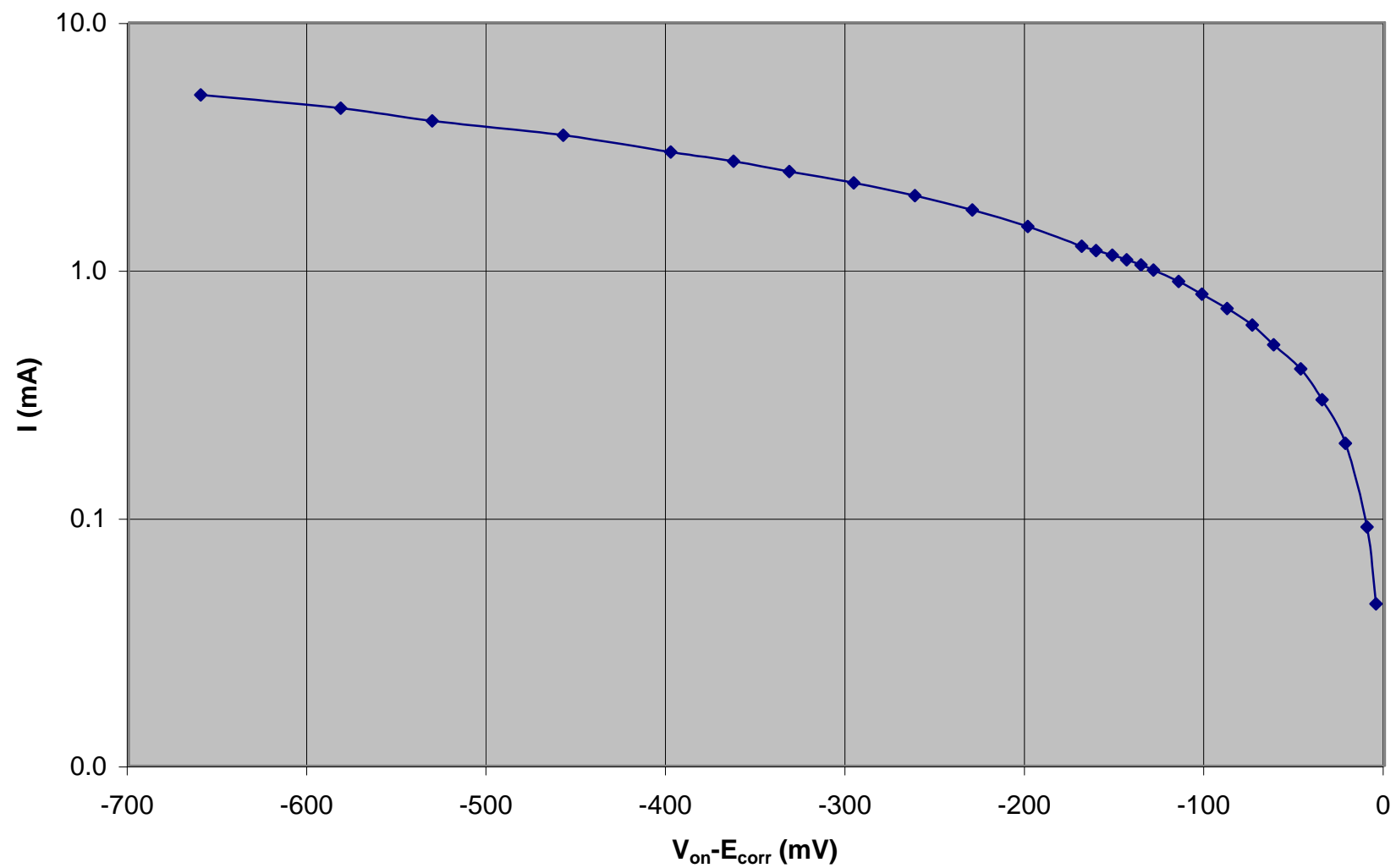
Tendon 5-1



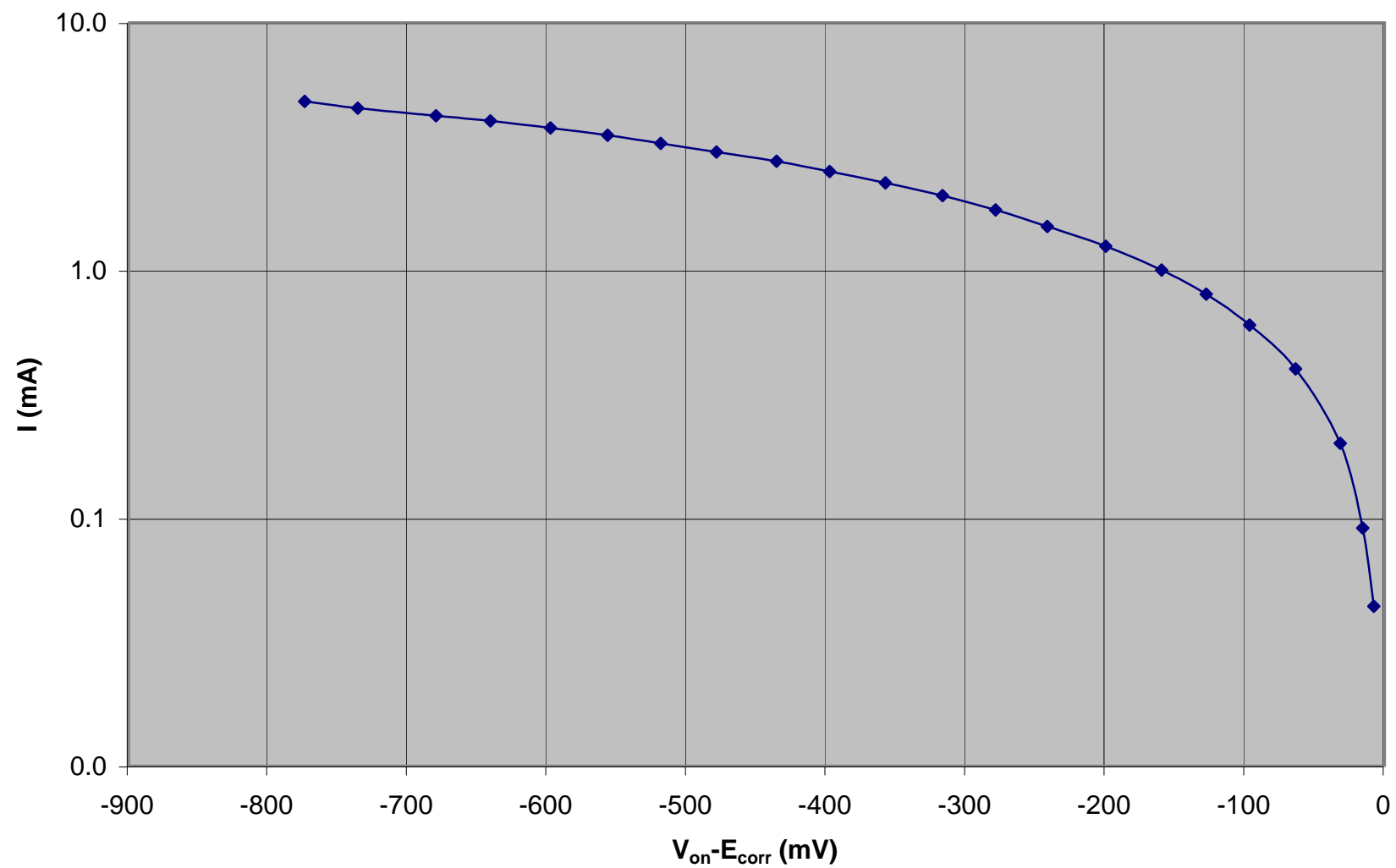
Tendon 5-2



Tendon 5-3



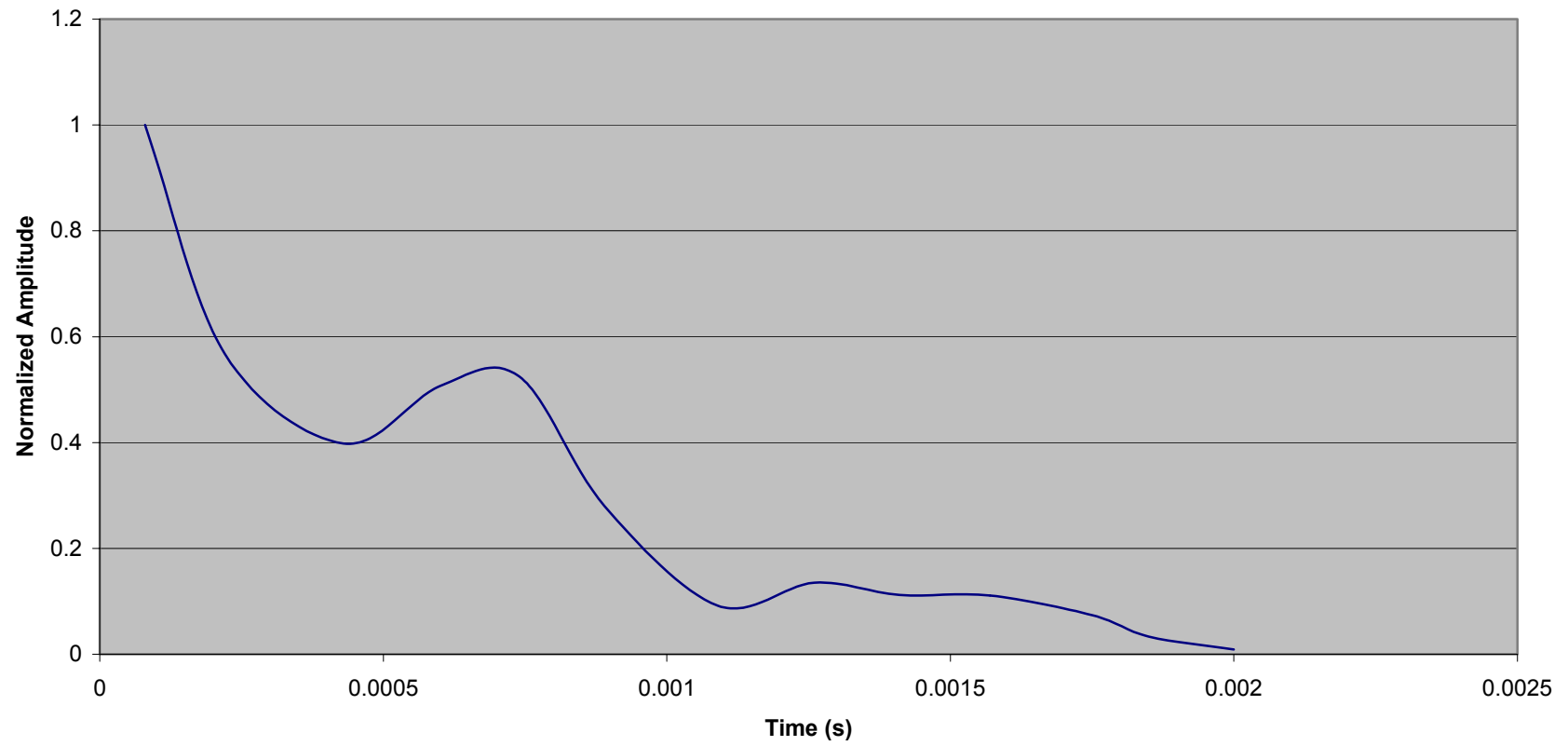
Tendon 5-4



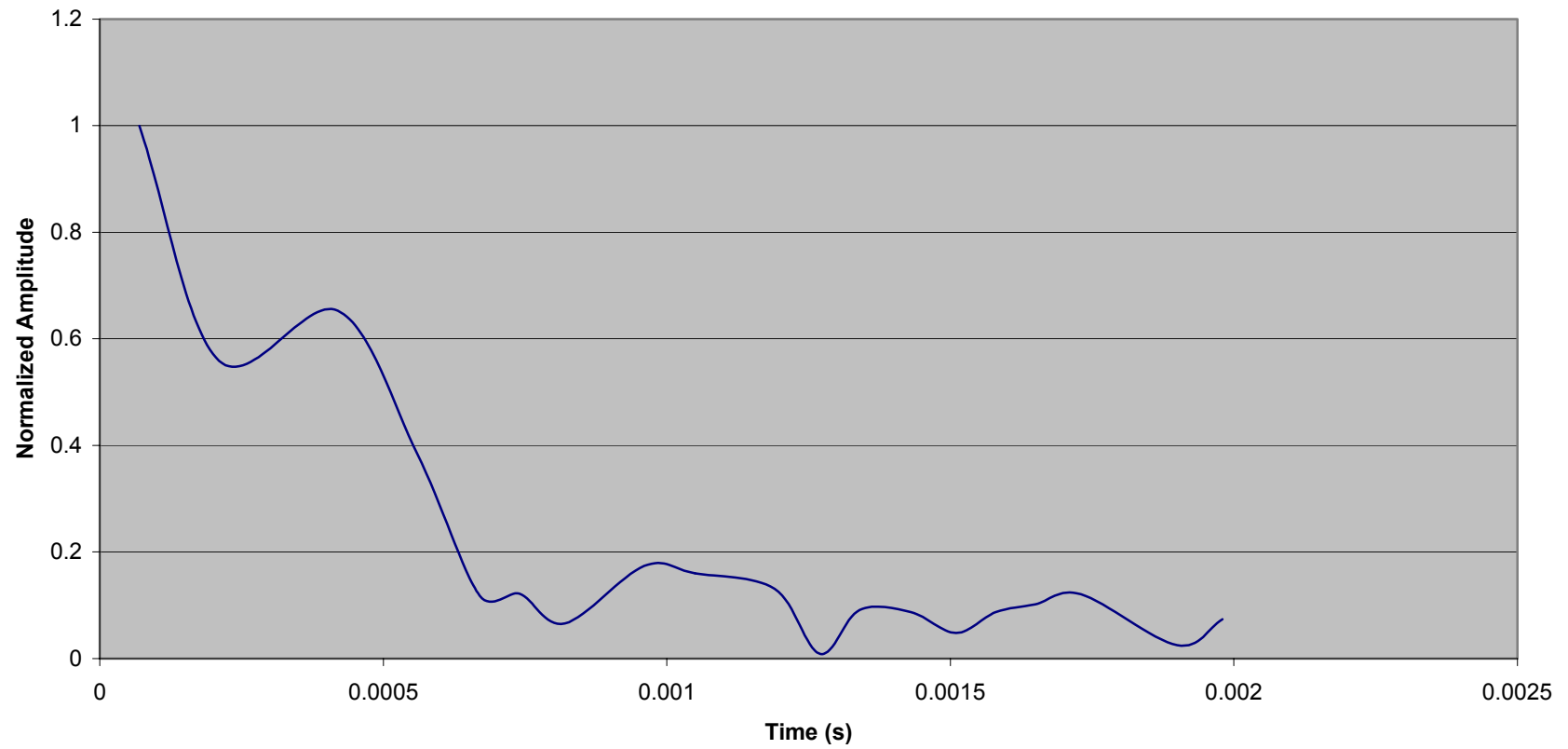
APPENDIX VI

DAMPING ENVELOPES FOR ROCK BOLTS

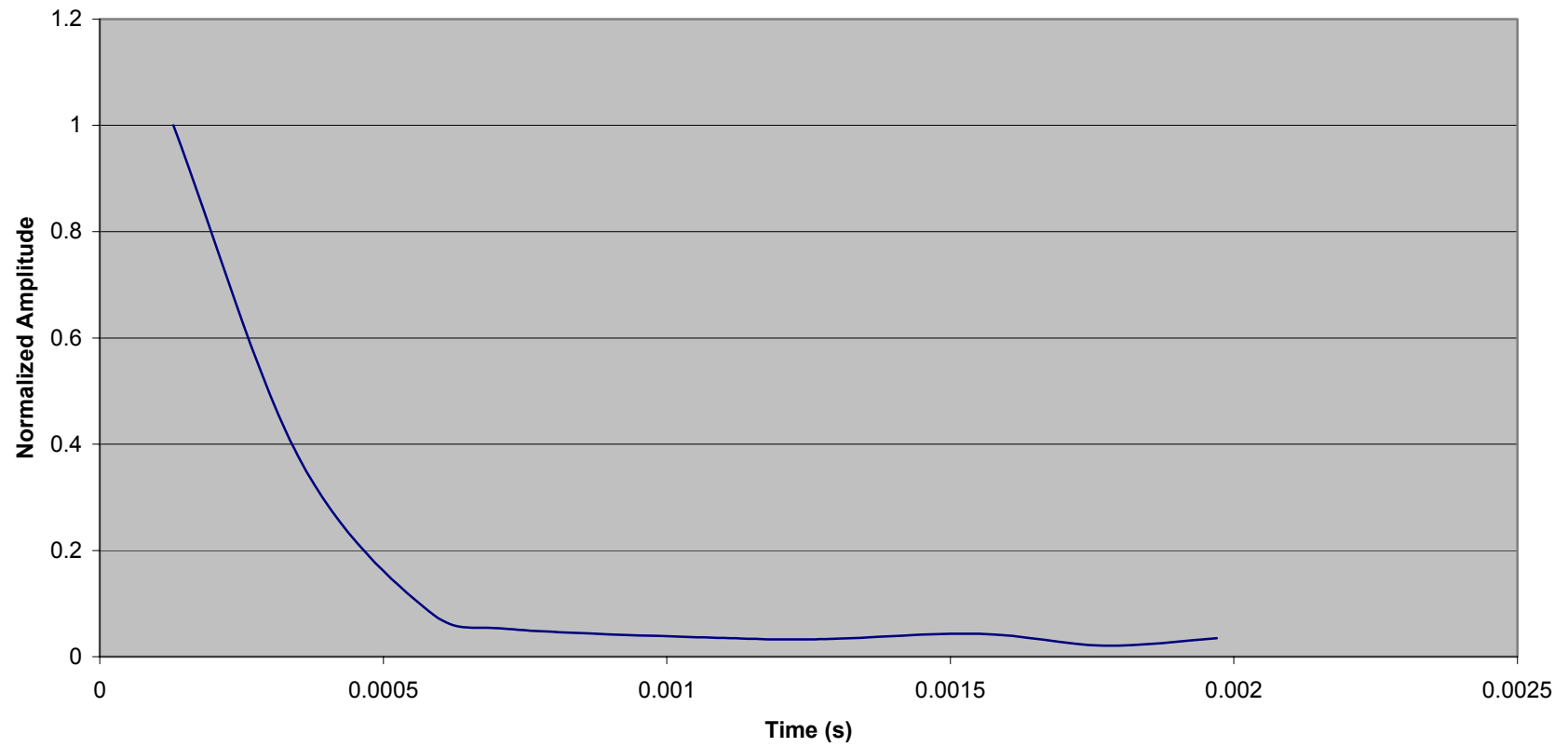
Barron Mountian Bolt #1 - Damping Envelope



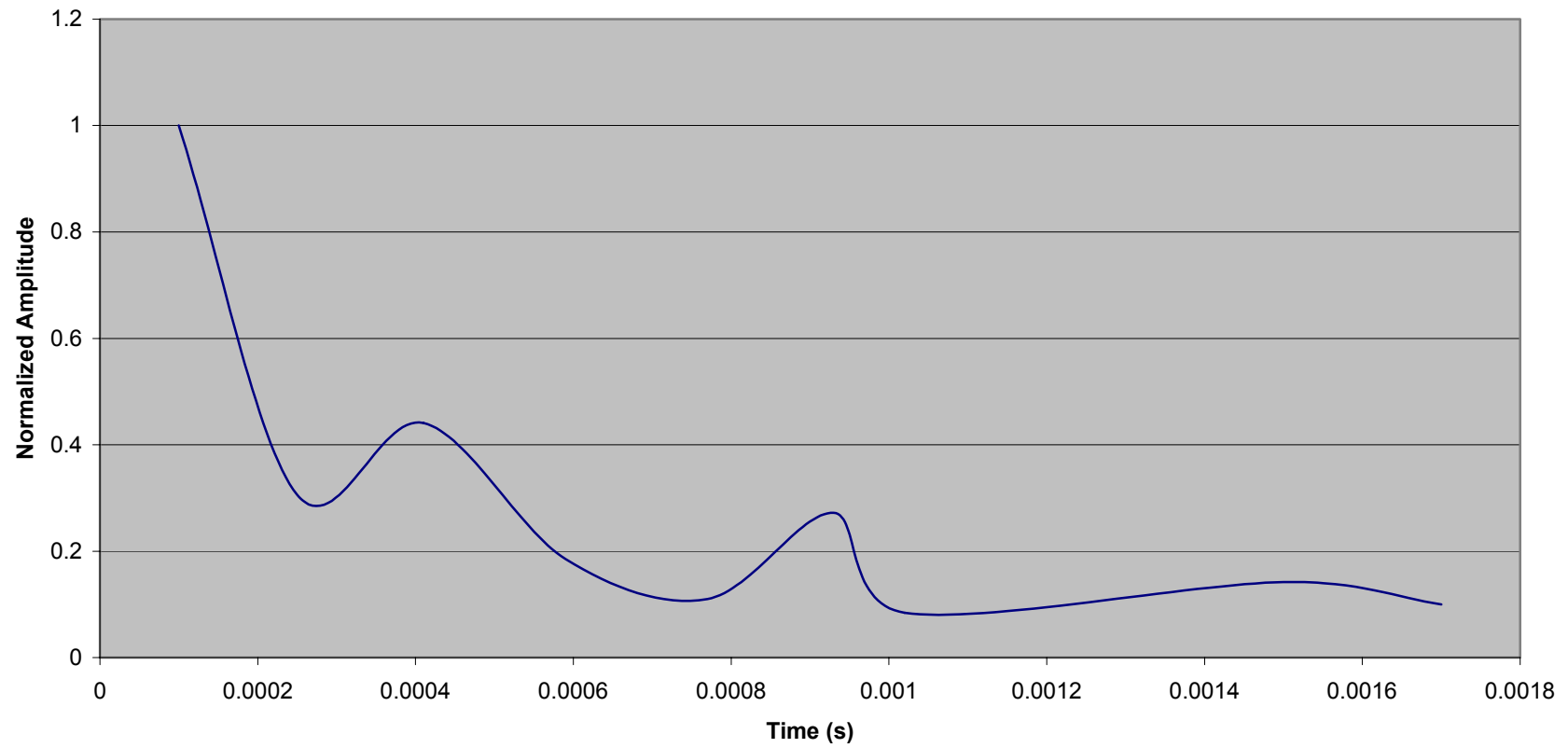
Barron Mountain Bolt #2 - Damping Envelope



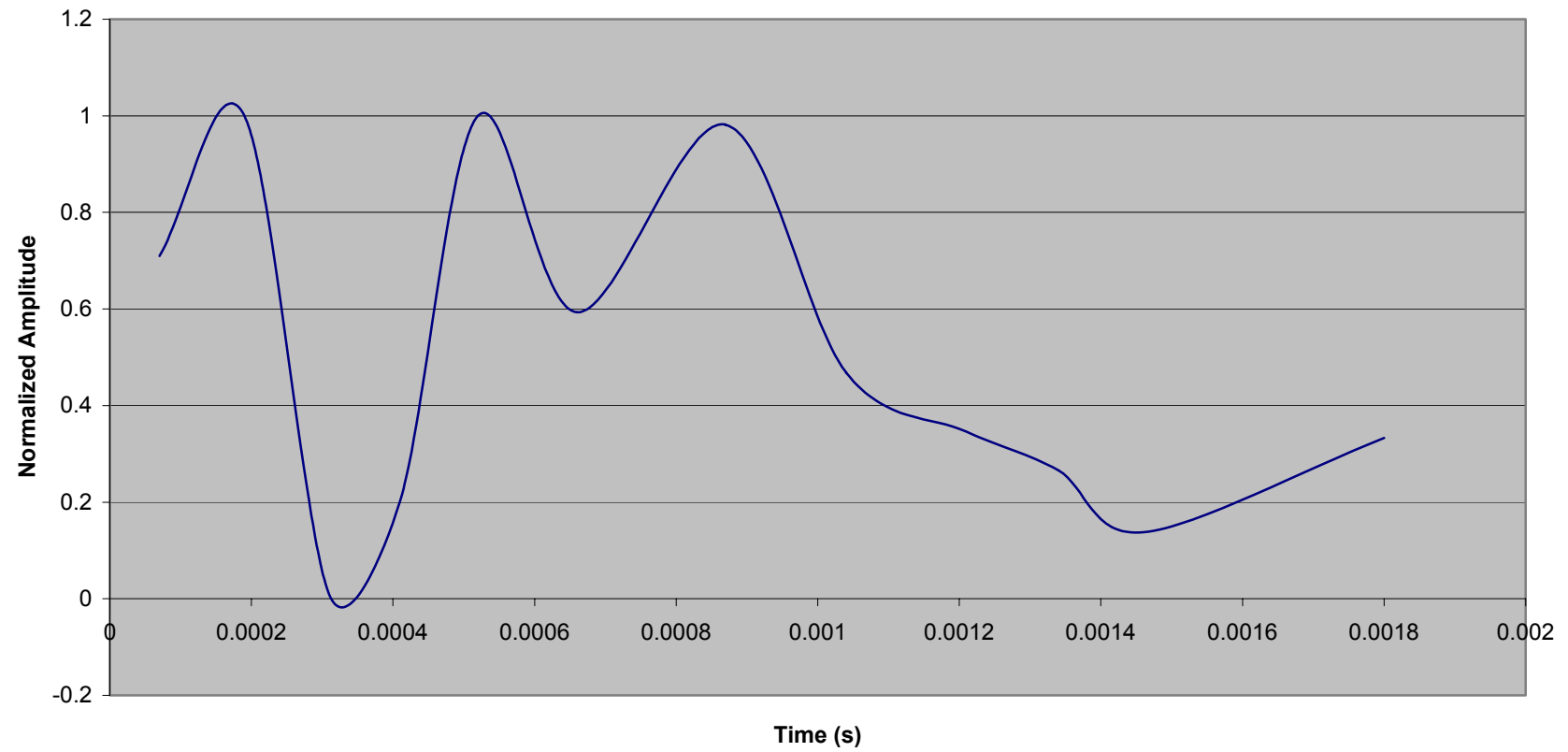
Barron Mountain Bolt #3 - Damping Envelope



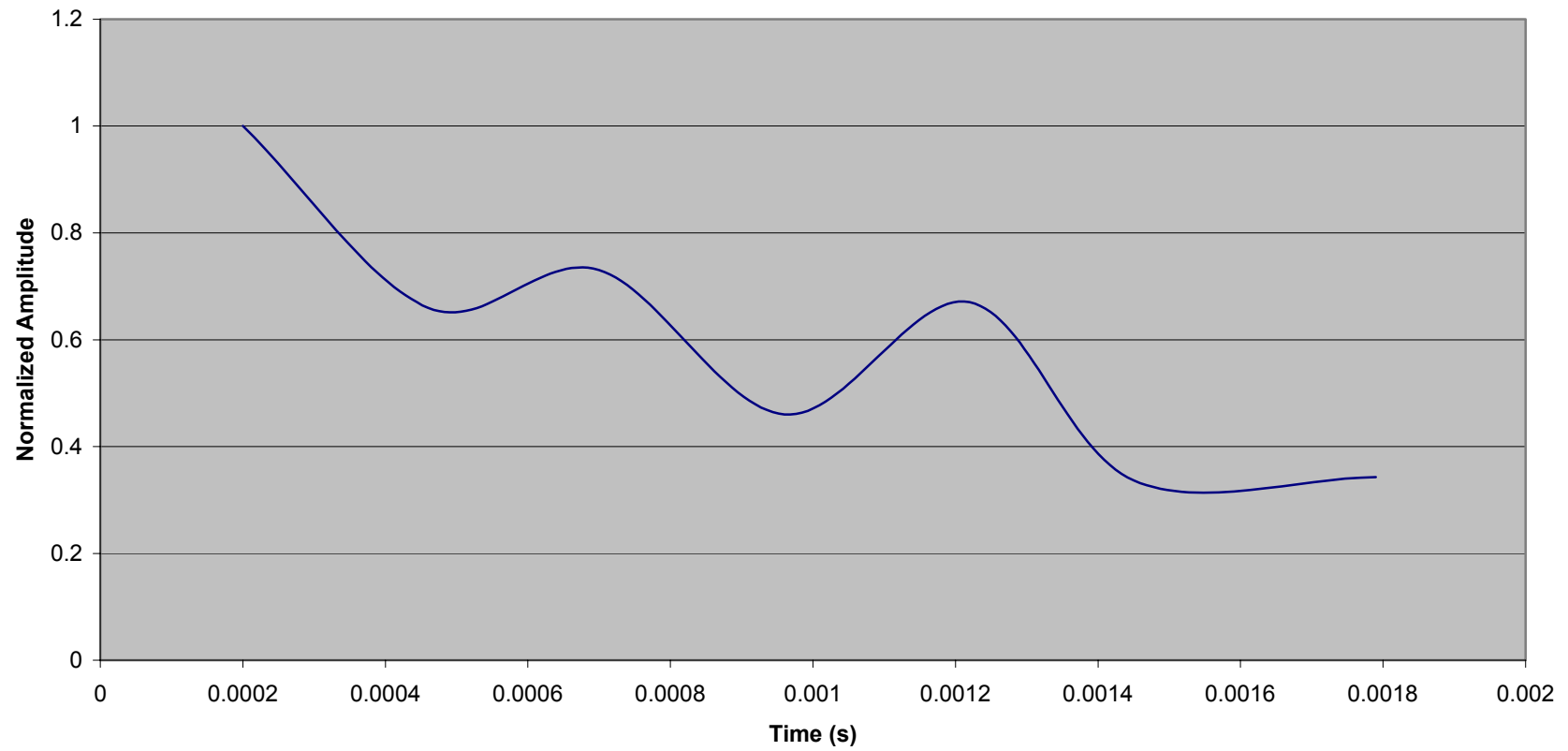
Barron Mountain Bolt #4 - Damping Envelope



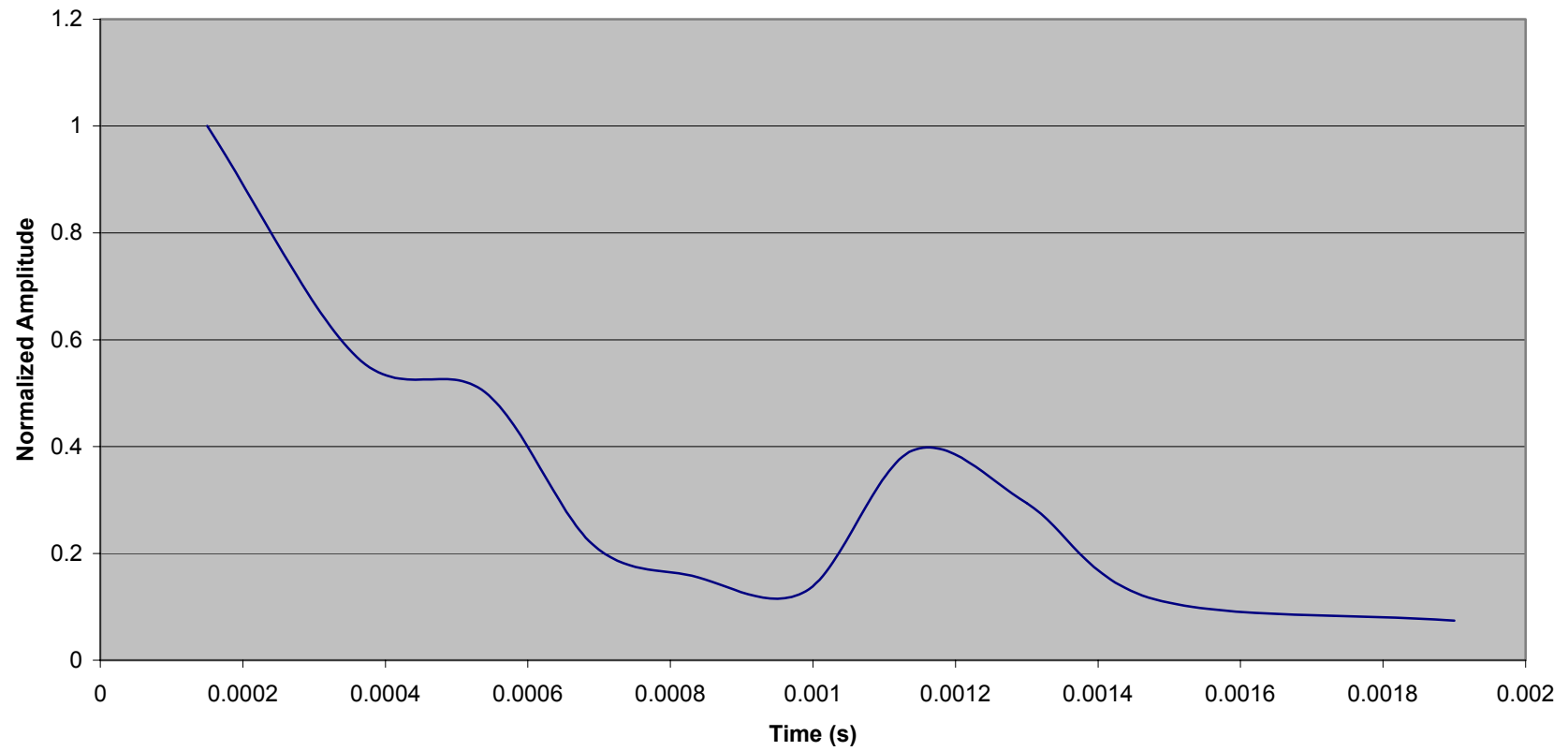
Barron Mountain Bolt #5 - Damping Envelope



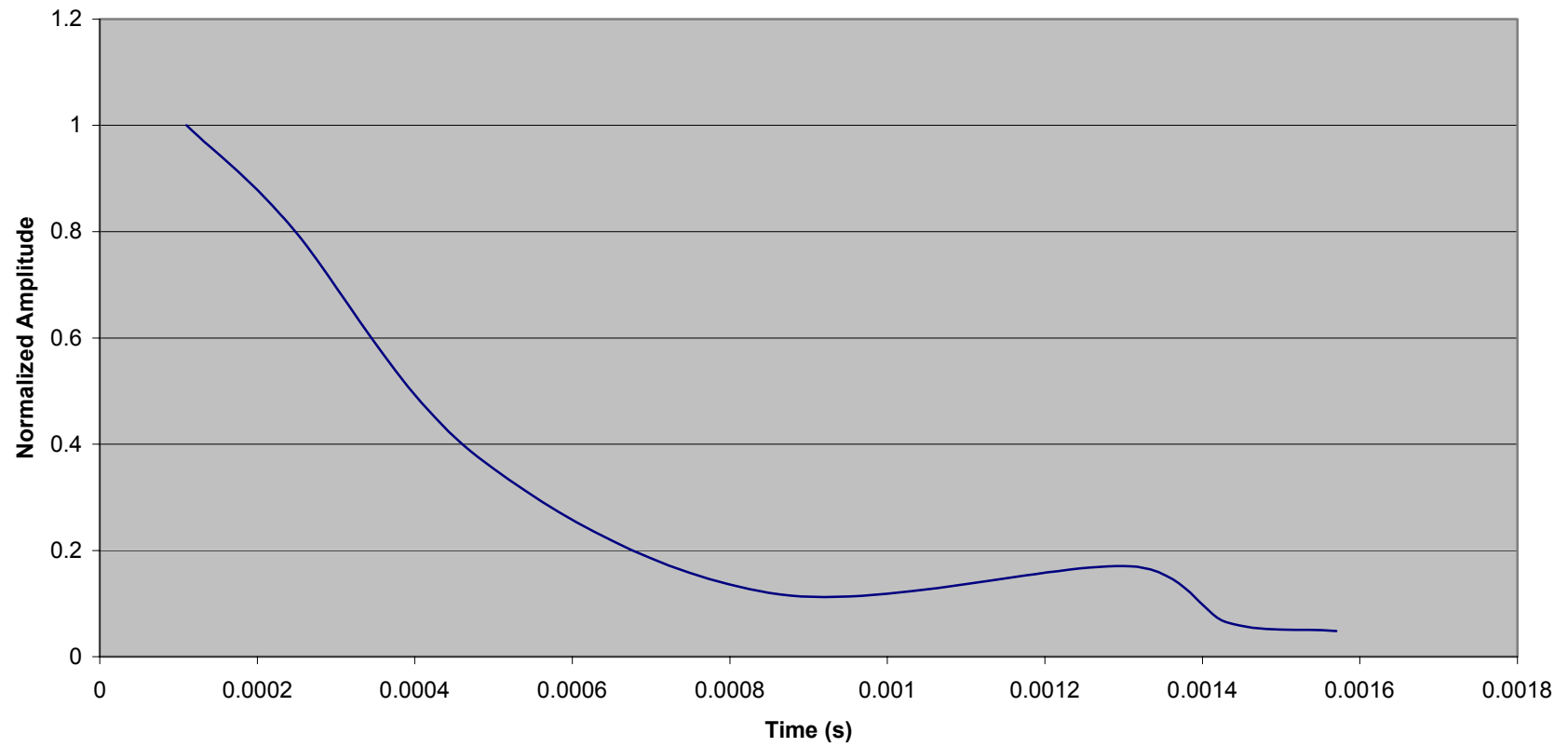
Barron Mountain Bolt # 6 - Damping Envelope



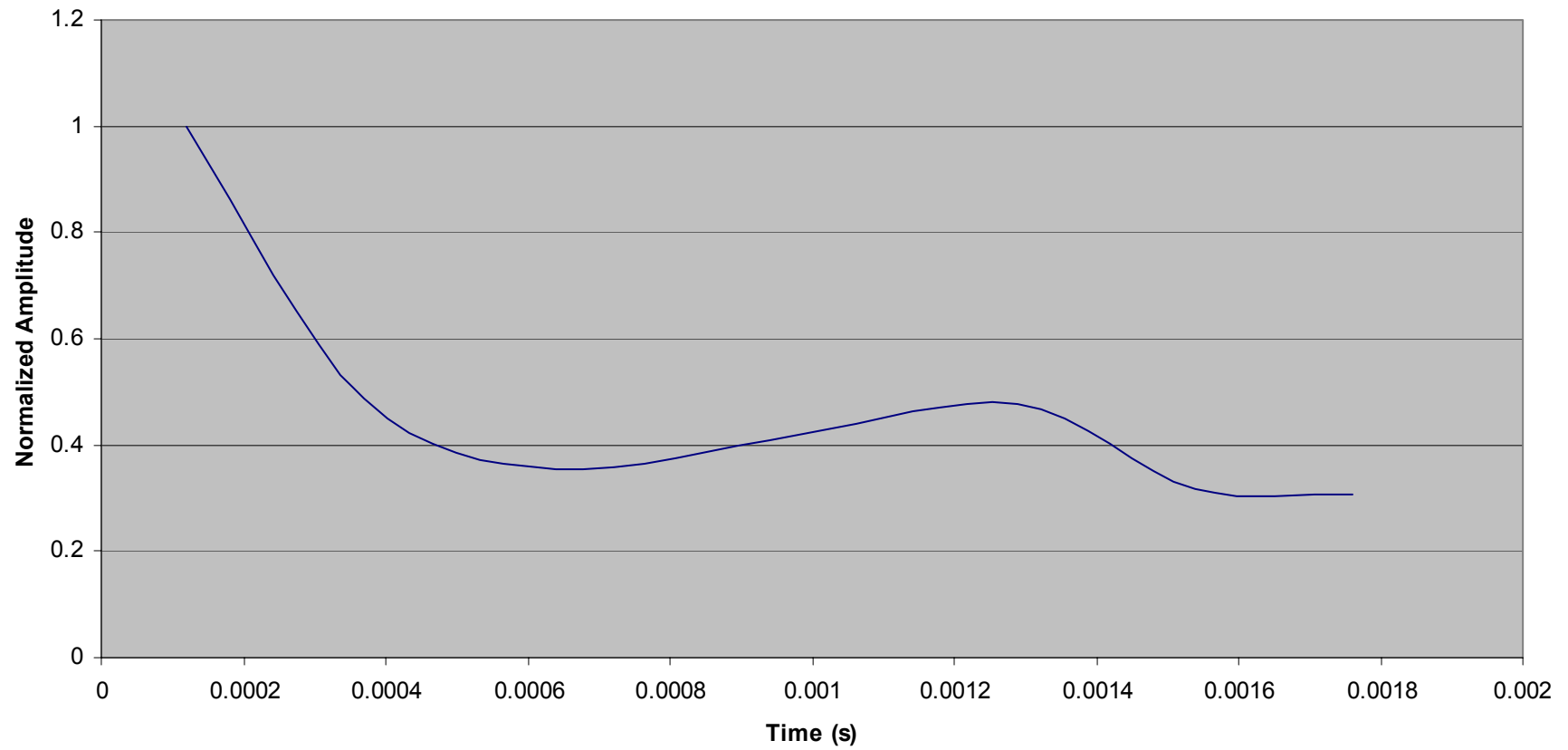
Barron Mountain Bolt #7 - Damping Envelope



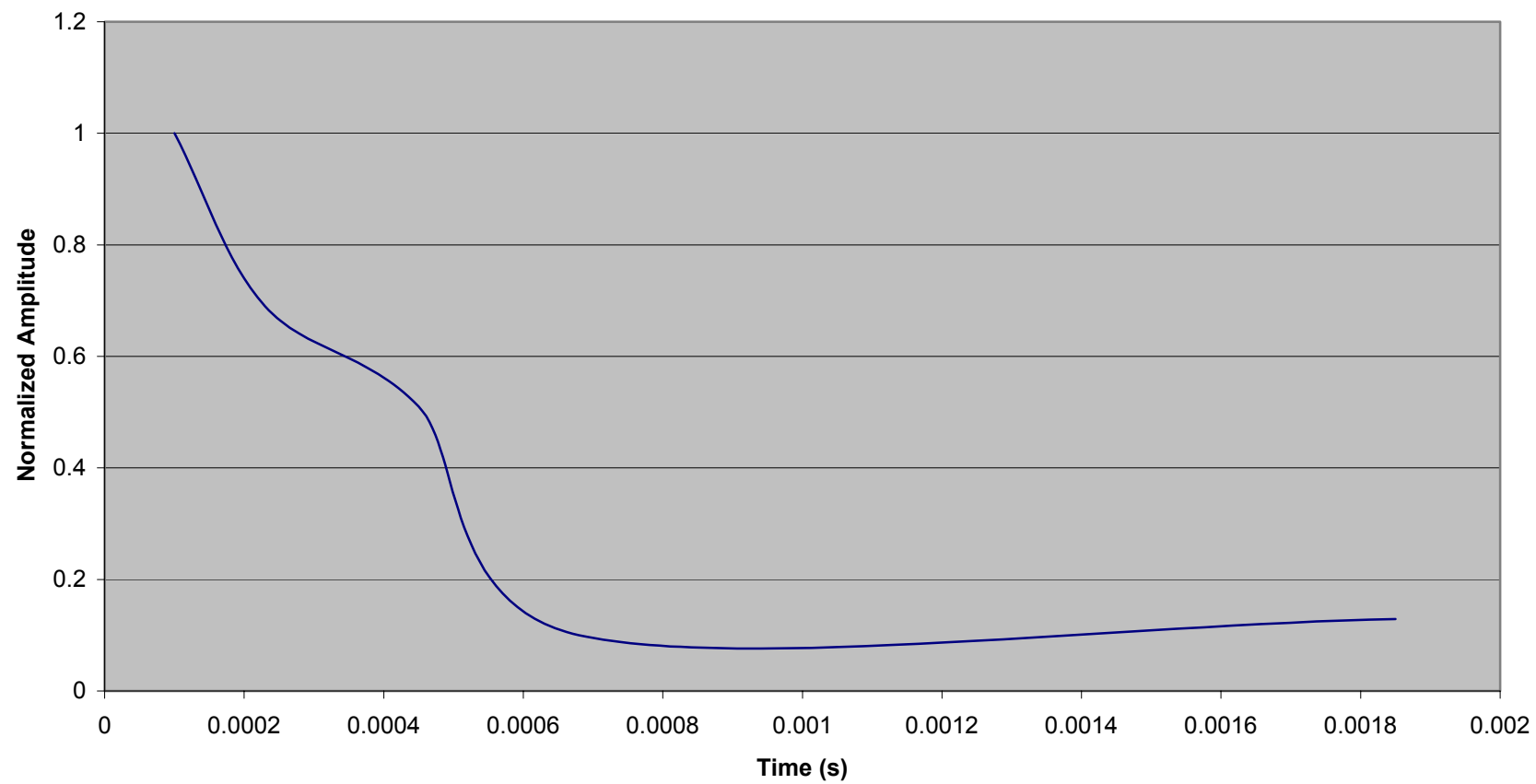
Barron Mountain Bolt #8 - Damping Envelope



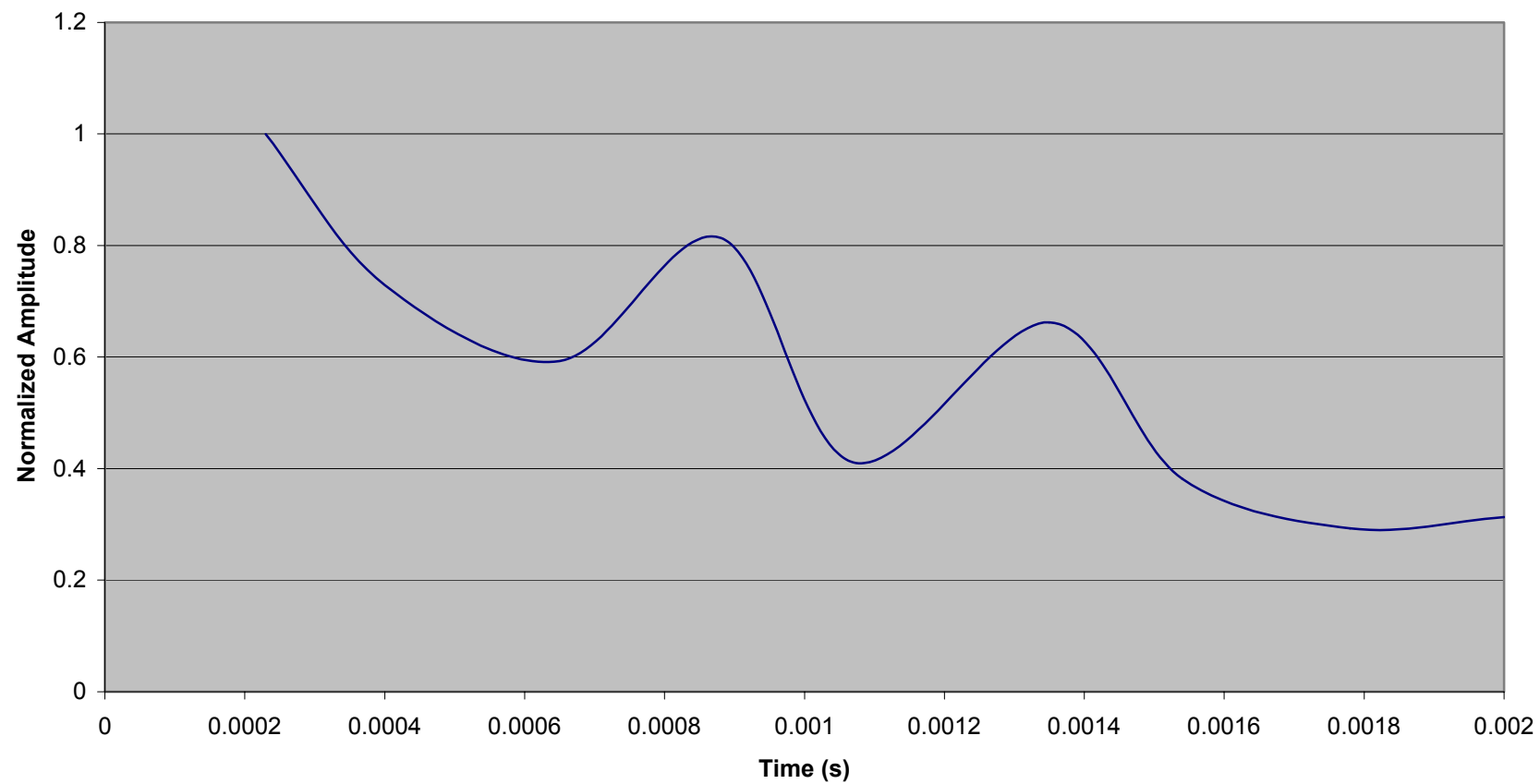
Barron Mountain Bolt #9 - Damping Envelope



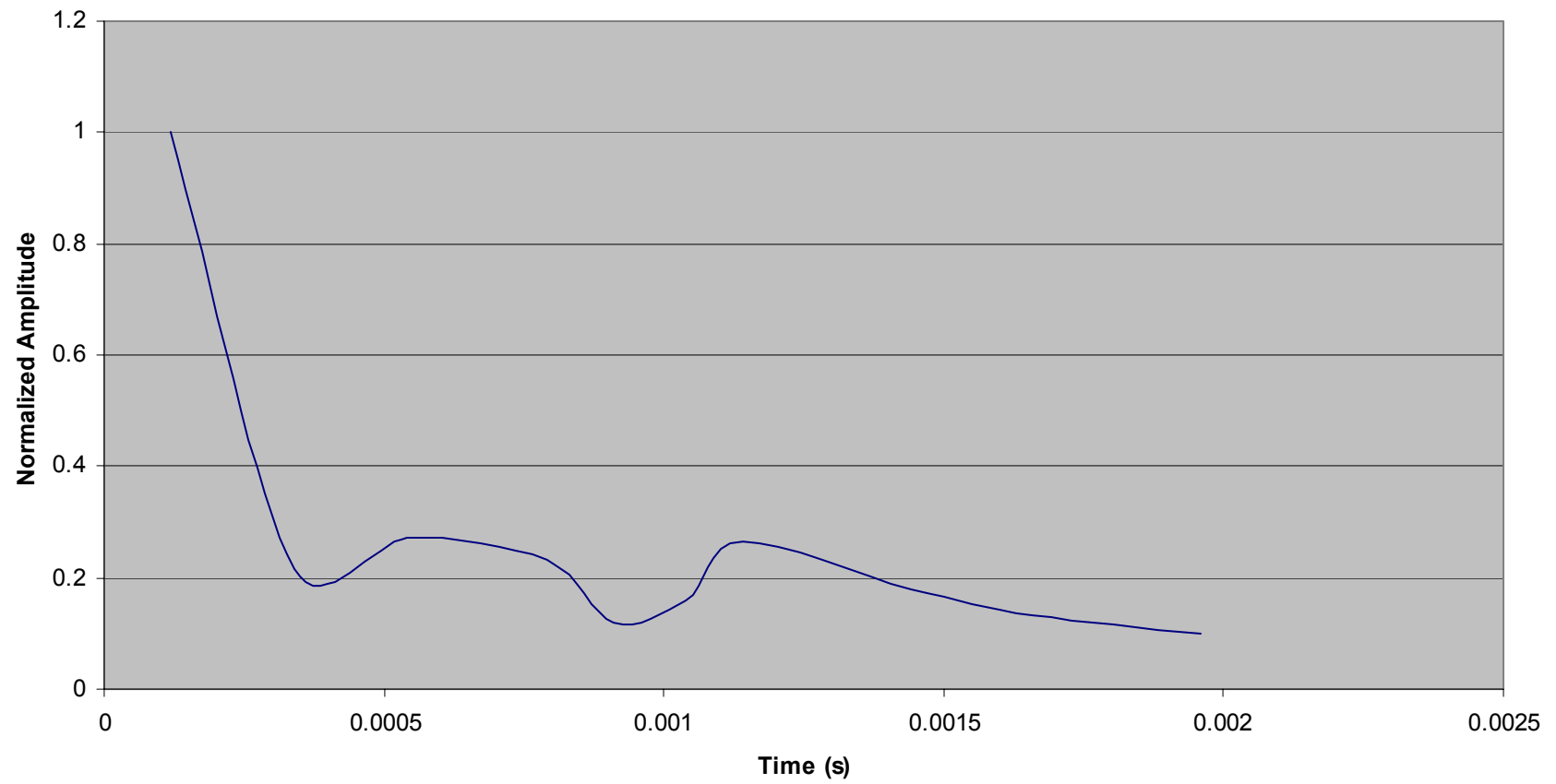
Barron Mountain Bolt #10 - Damping Envelope



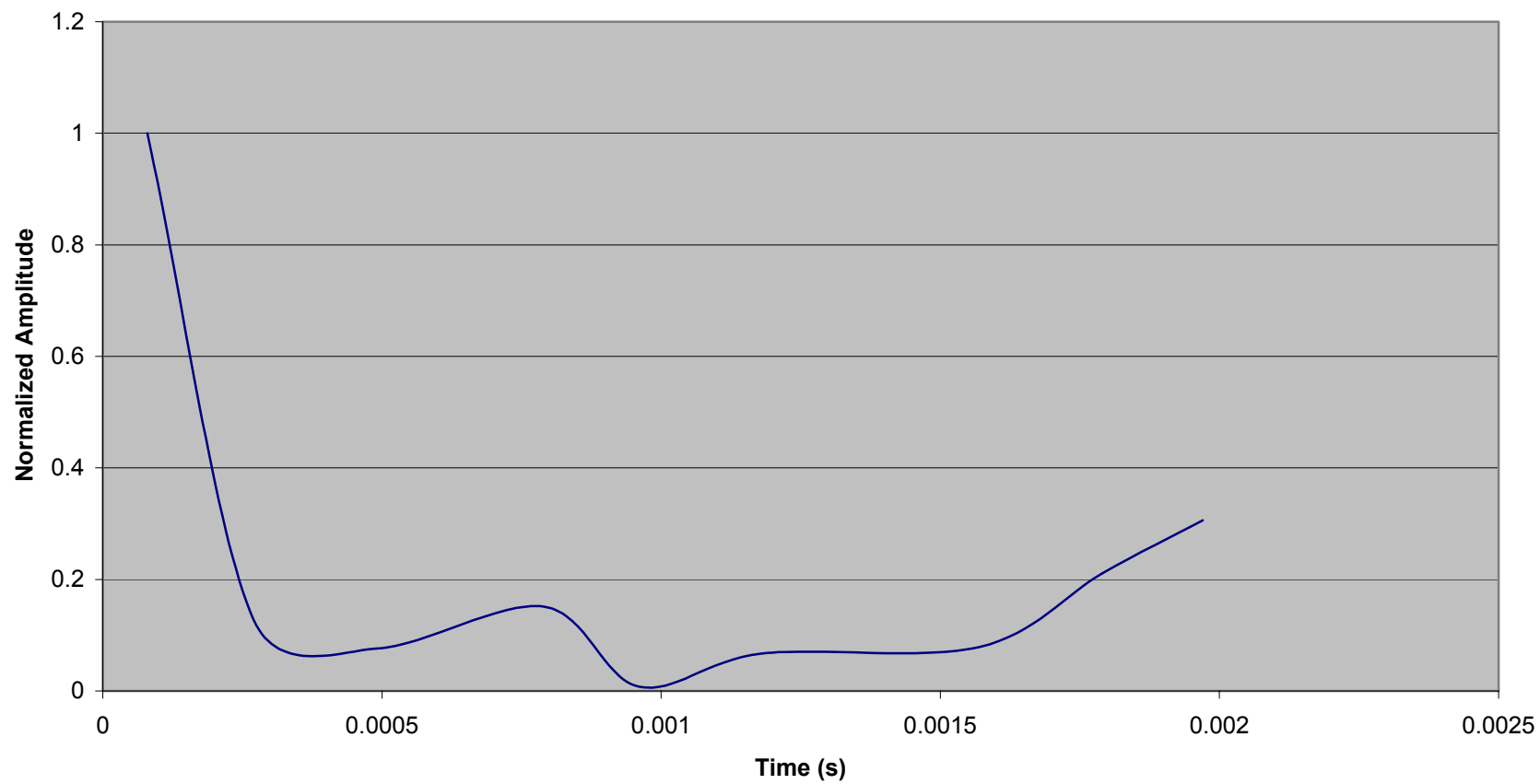
Barron Mountain Bolt #11 - Damping Envelope



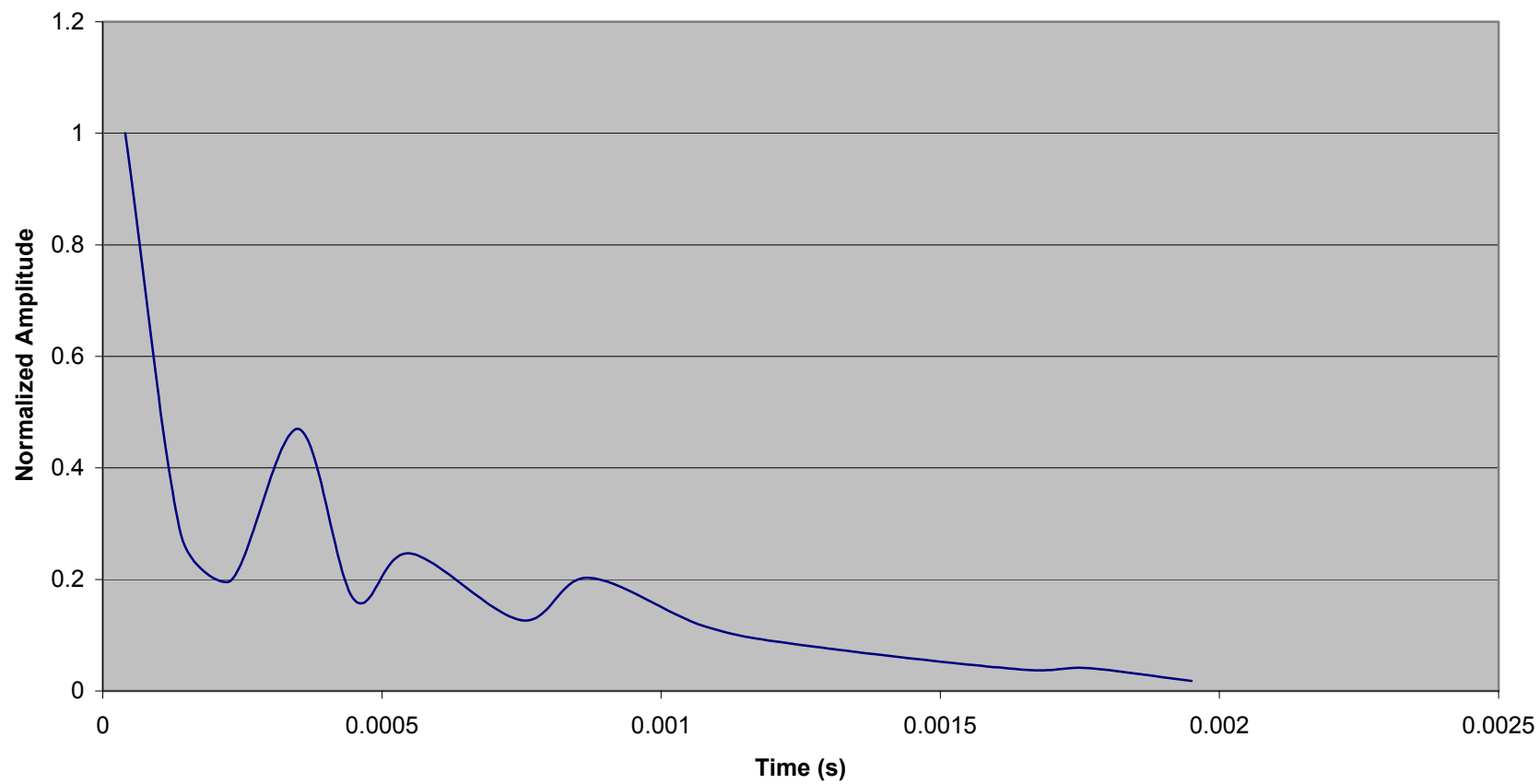
Barron Mountain Bolt #13- Damping Envelope



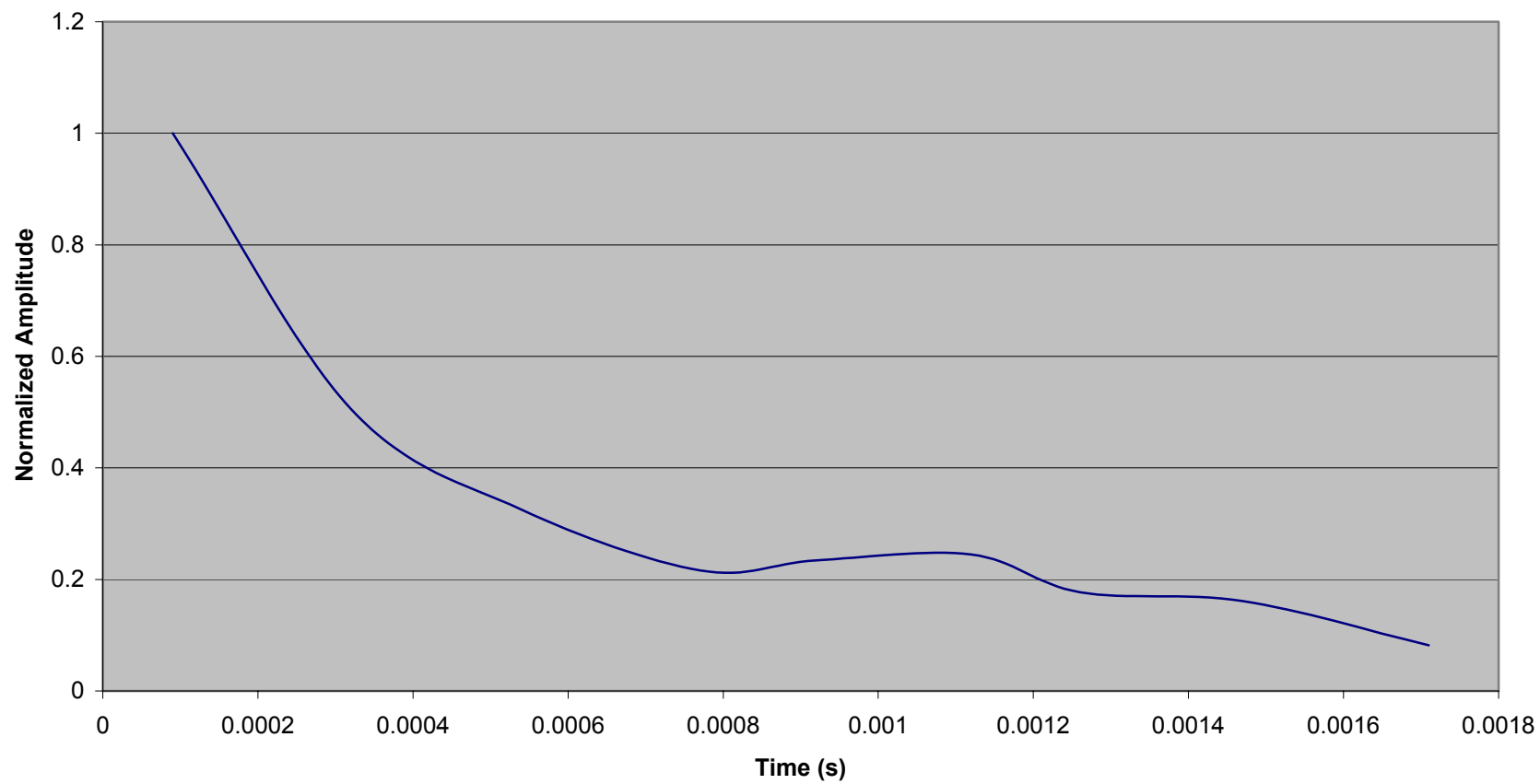
Barron Mountain Bolt #14 - Damping Envelope



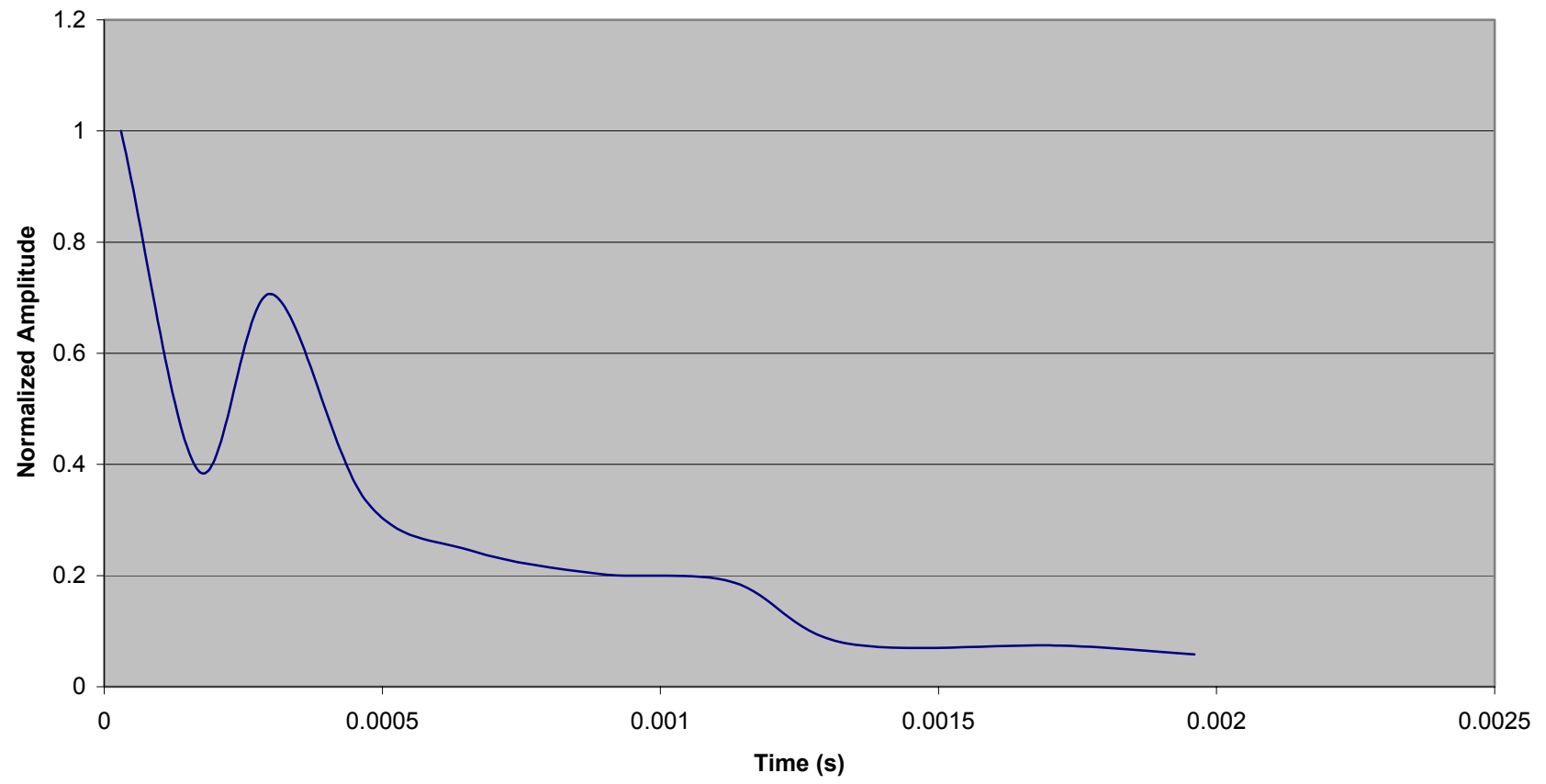
Barron Mountain Bolt #15 - Damping Envelope



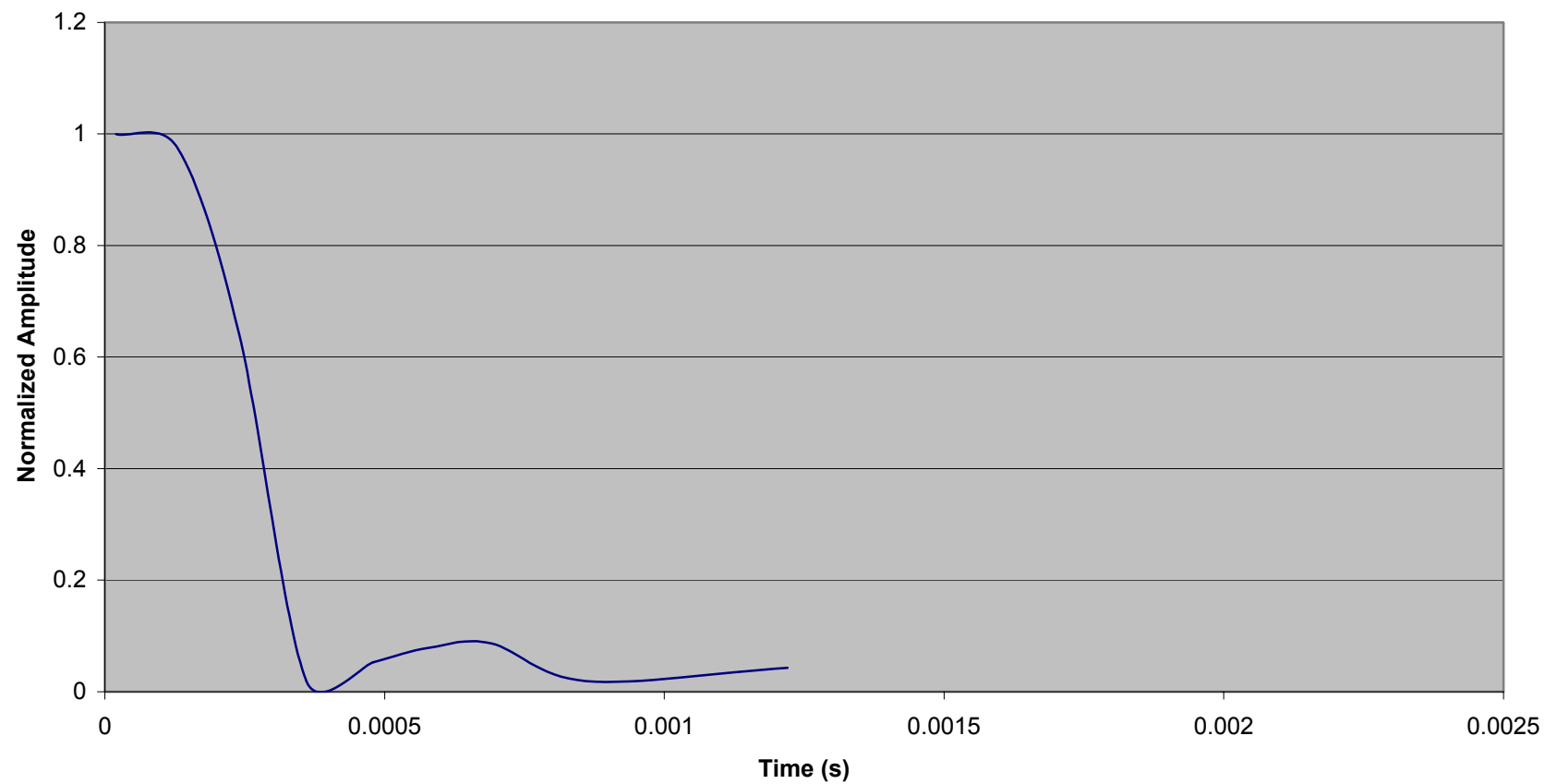
Barron Mountain Bolt #16 - Damping Envelope



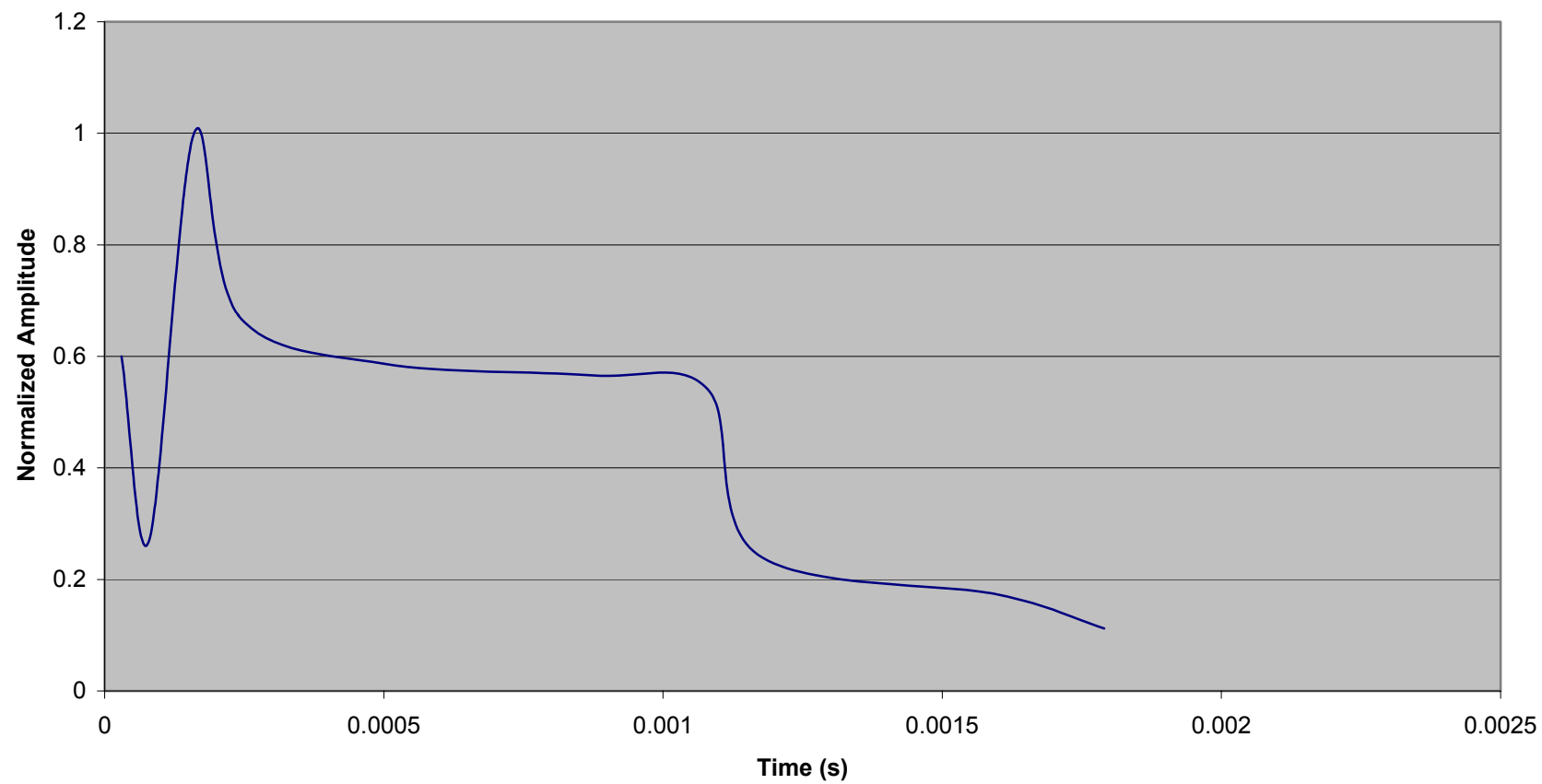
Barron Mountain Bolt #17 - Damping Envelope



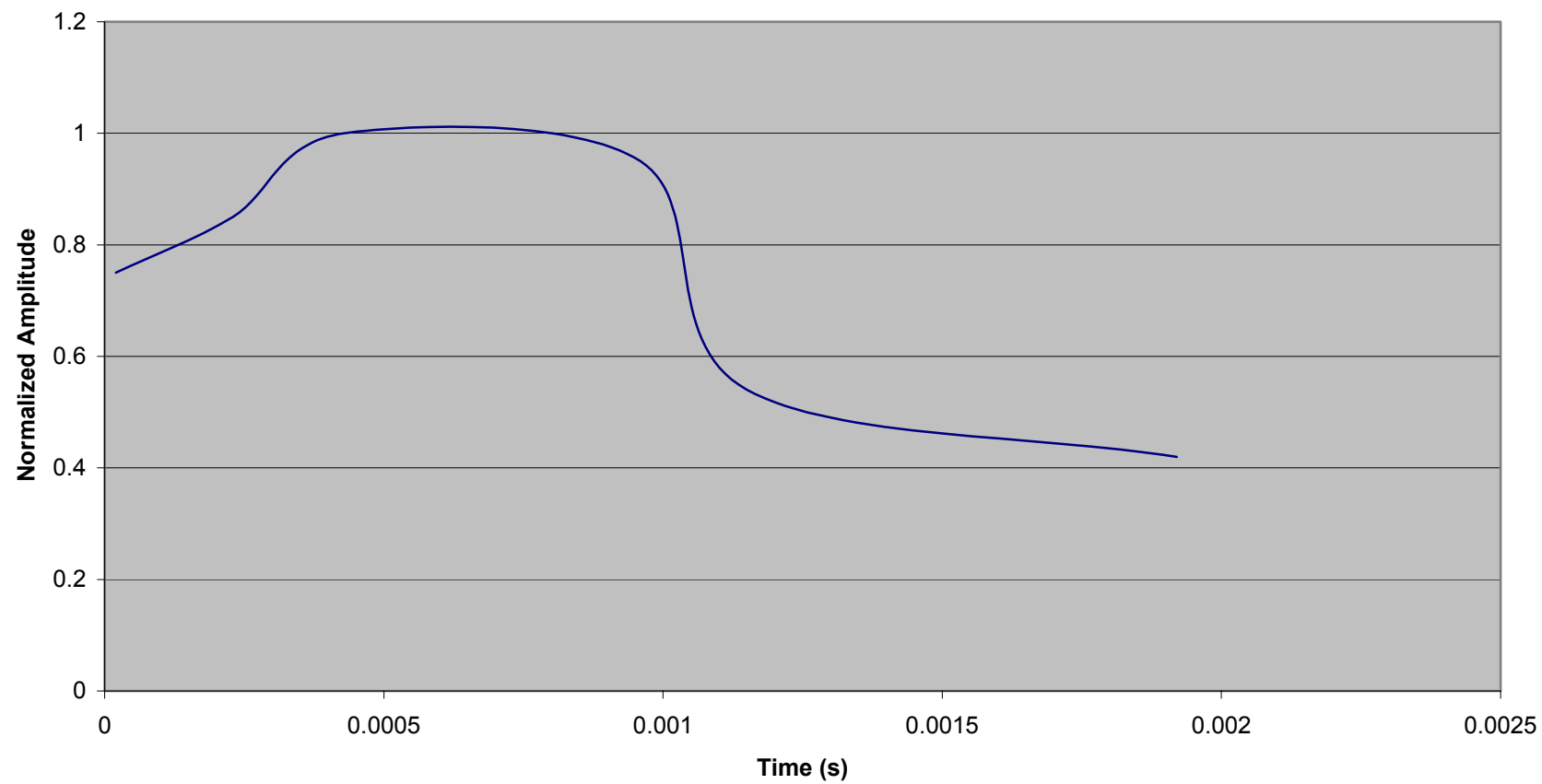
Barron Mountain Bolt #18 - Damping Envelope



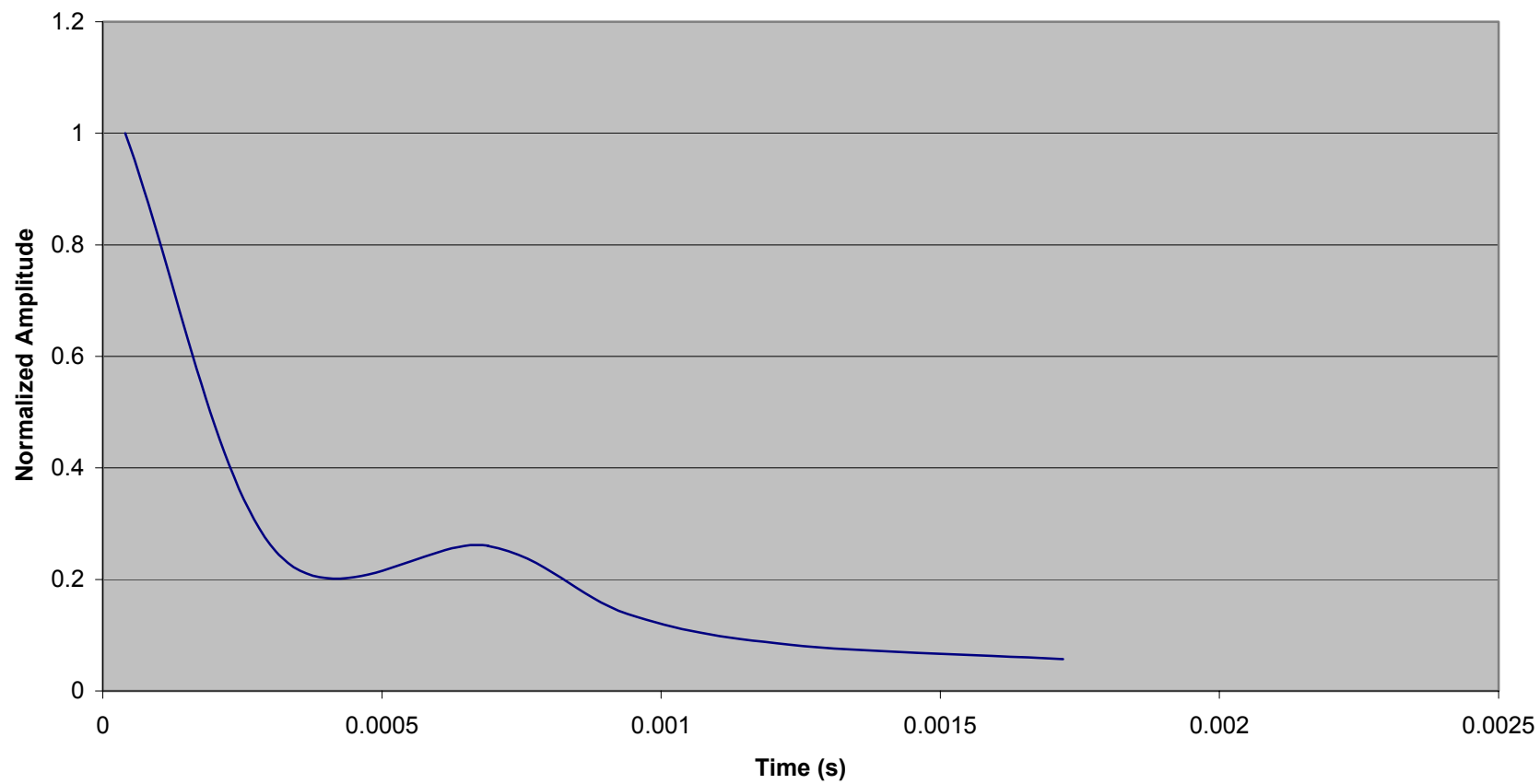
Barron Mountain Bolt #19 - Damping Envelope



Barron Mountain Bolt #20 - Damping Envelope



Barron Mountain Bolt 21a - Damping Envelope



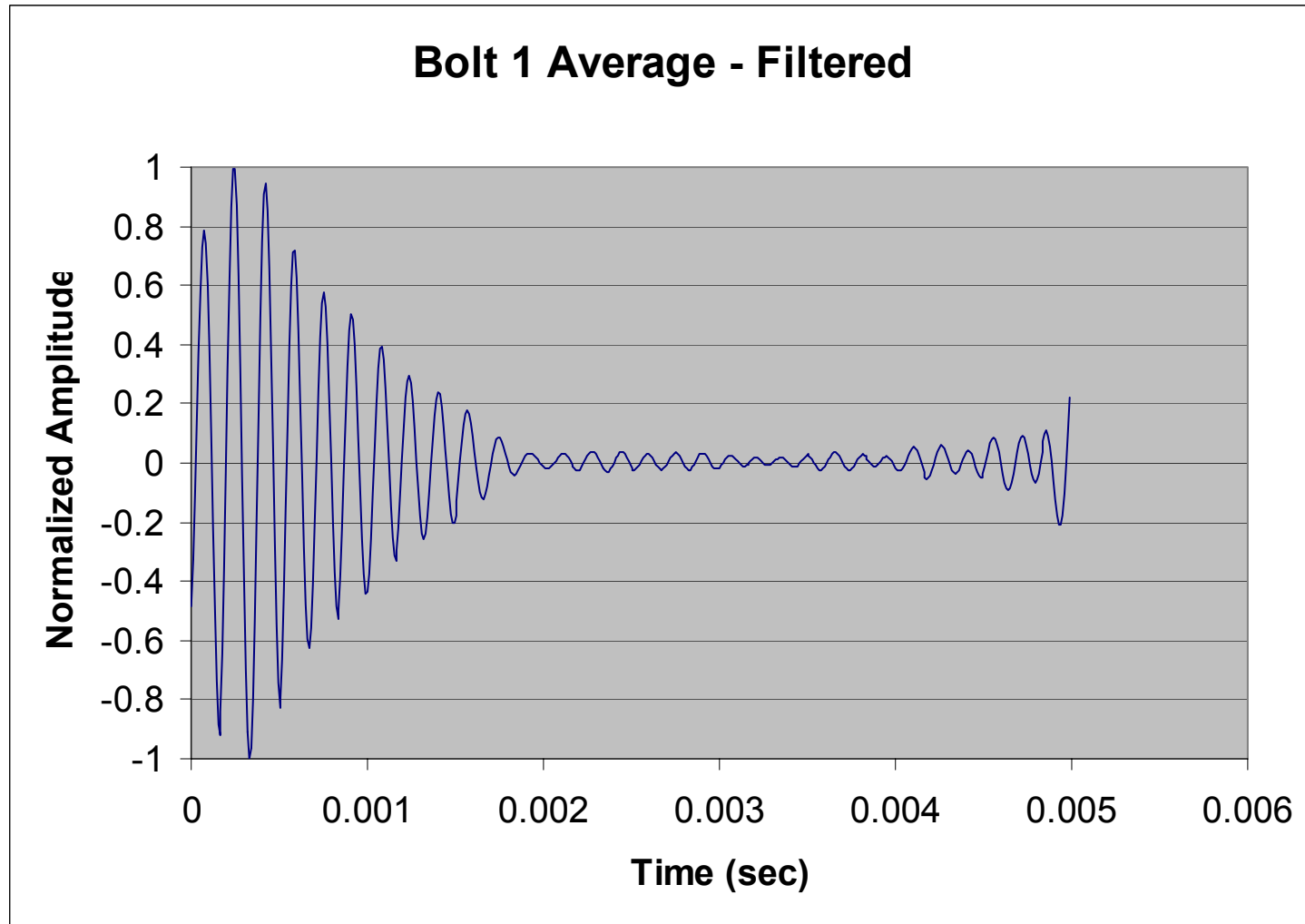
APPENDIX VII

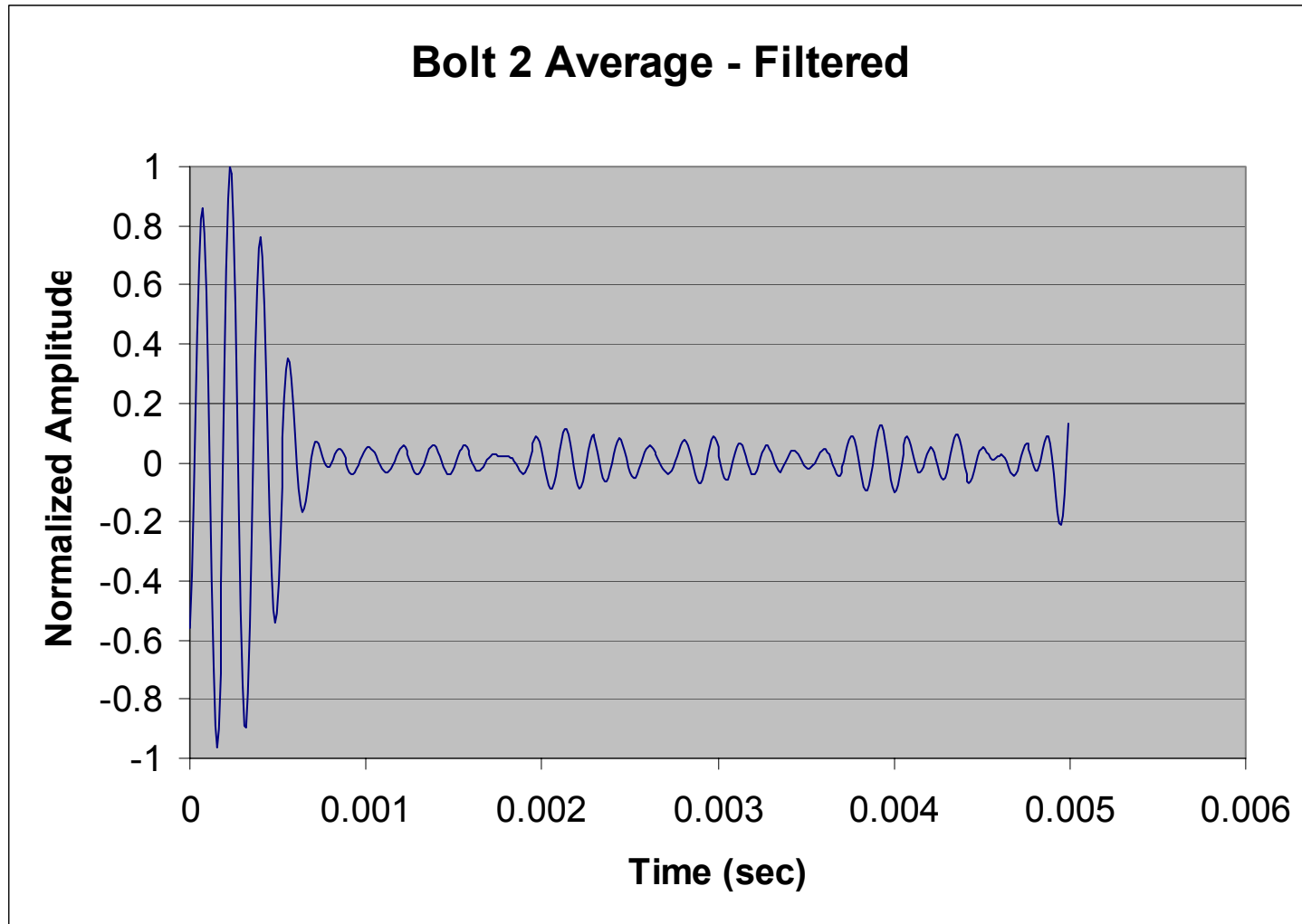
ROCK BOLTS

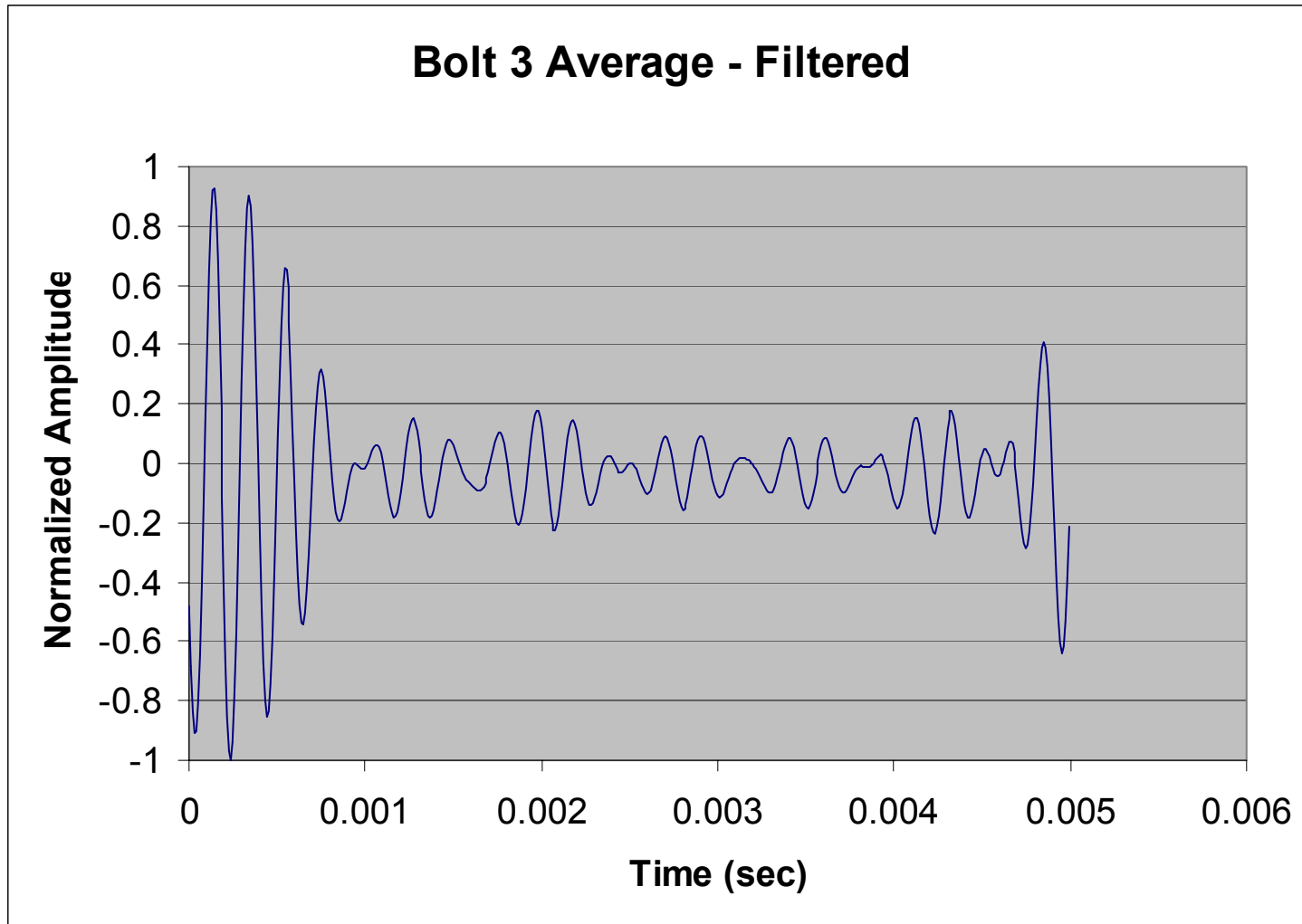
IMPACT ACCELERATION TIME HISTORIES

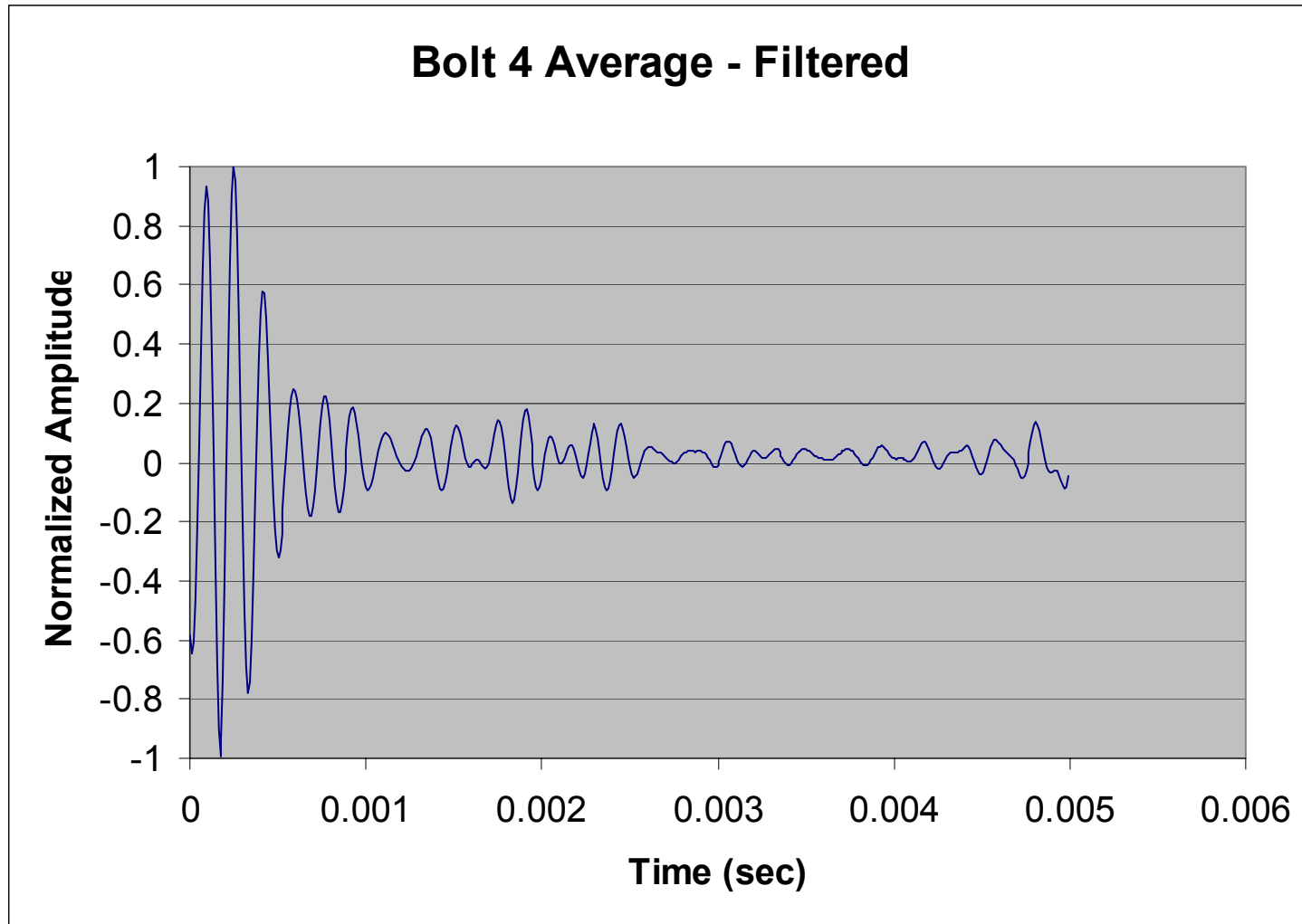
Table VII-1. Observed Reflections from Impact Test on Rock Bolts.

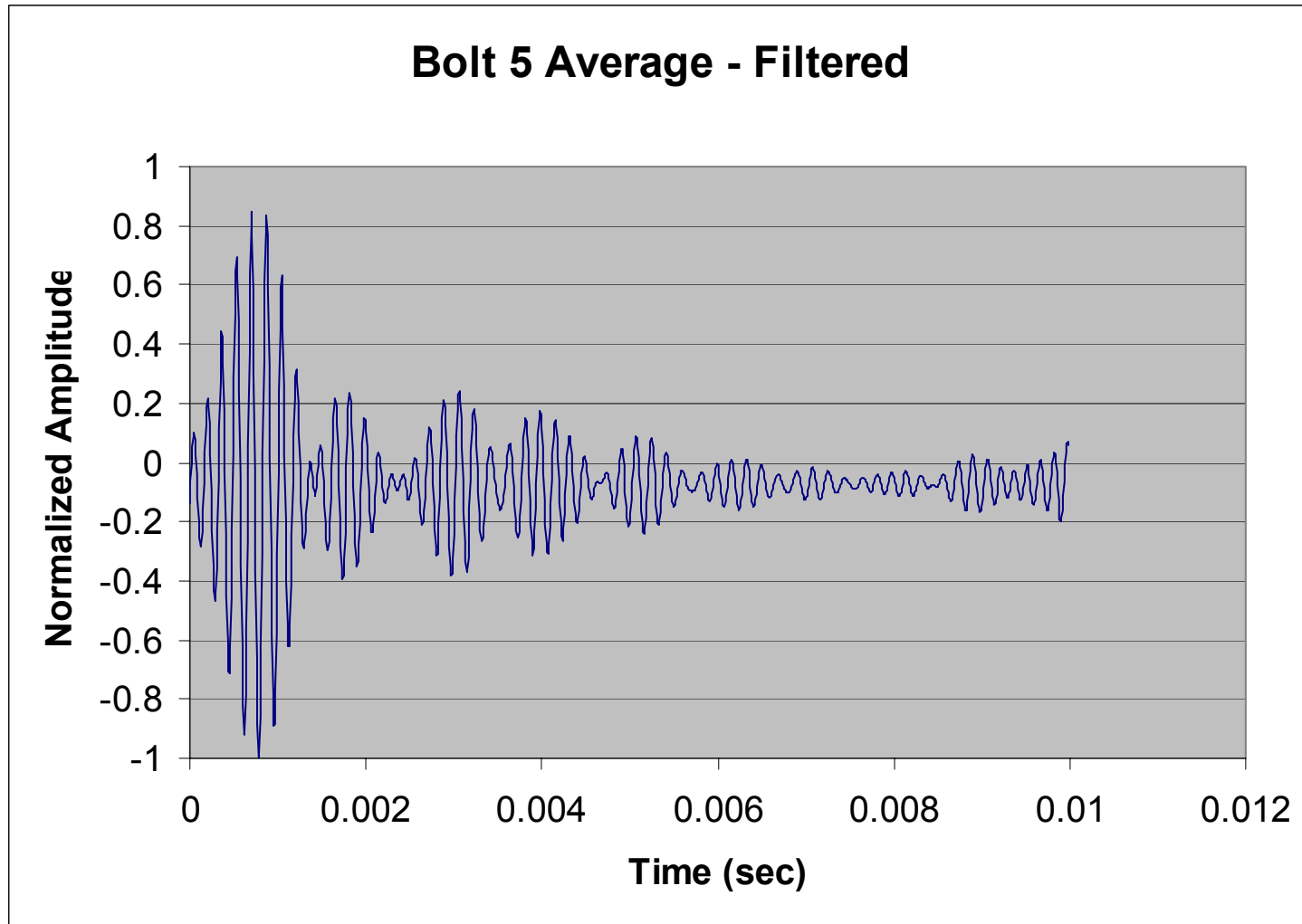
Test Bolt #	Relative Signal Attenuation	Observed L_1 (ft)	Observed L_2 (ft)	"Known" L_T (ft)
1	Strong	~	16	15
2	Strong	7	17	25
3	Strong	10	15	25
4	Strong	5	15	30
5	Weak	8	~	25
6	Weak	7	~	15
7	Weak	~	7	10
8	Weak	~	9	10
9	Weak	~	10	10
10	Strong	~	16	15
11	Strong	15	26	25
12	Weak	8	~	25
13	Strong	12	33	30
14	Weak	10	33	30
15	Weak	14	~	20
16	Weak	8	17	20
17	Weak	11	25	25
18	Weak	12	28	25
19	Strong	~	20	20
20	Weak	13	17	20
21	Weak	~	12	10
22	Weak	8	25	25

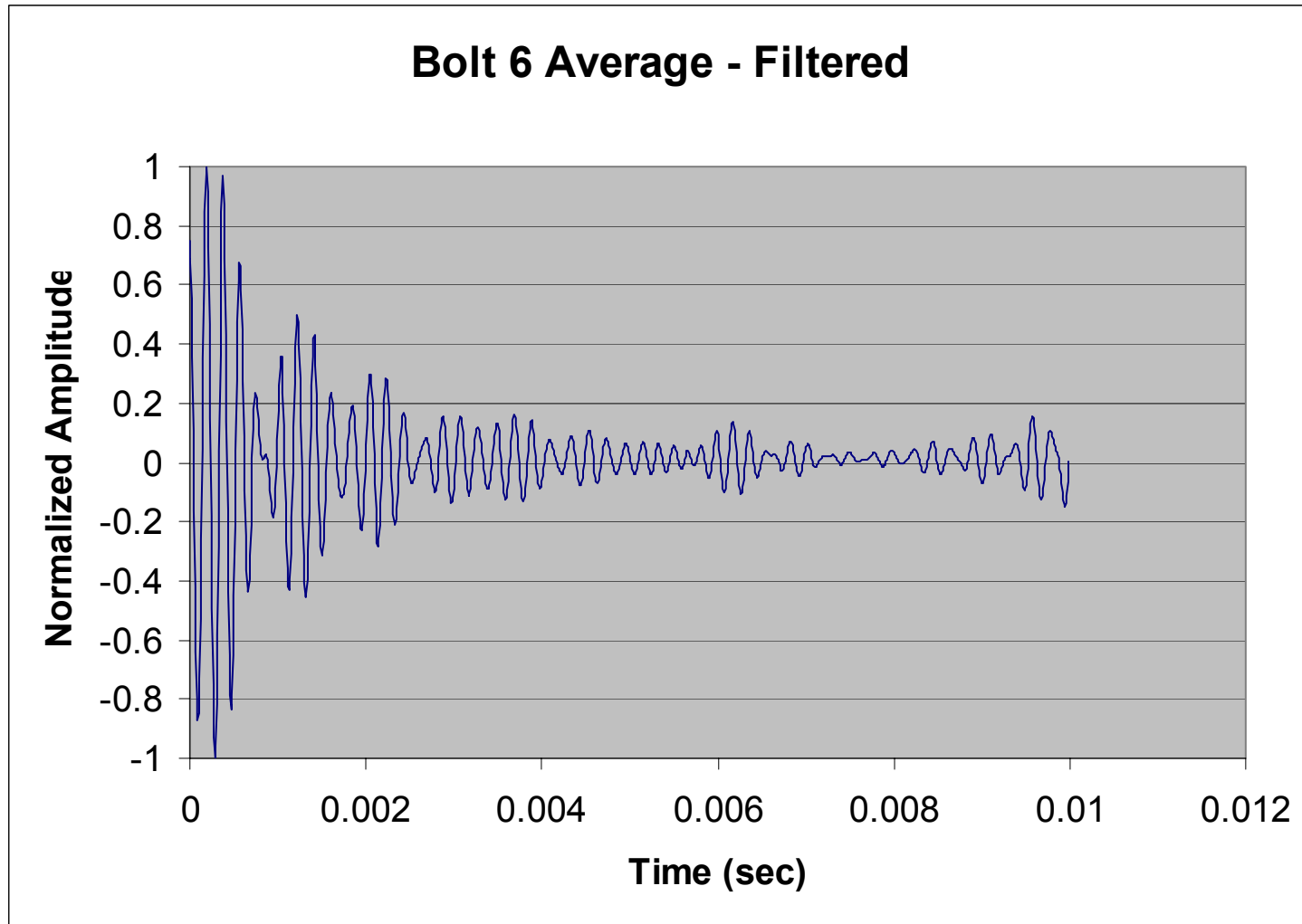


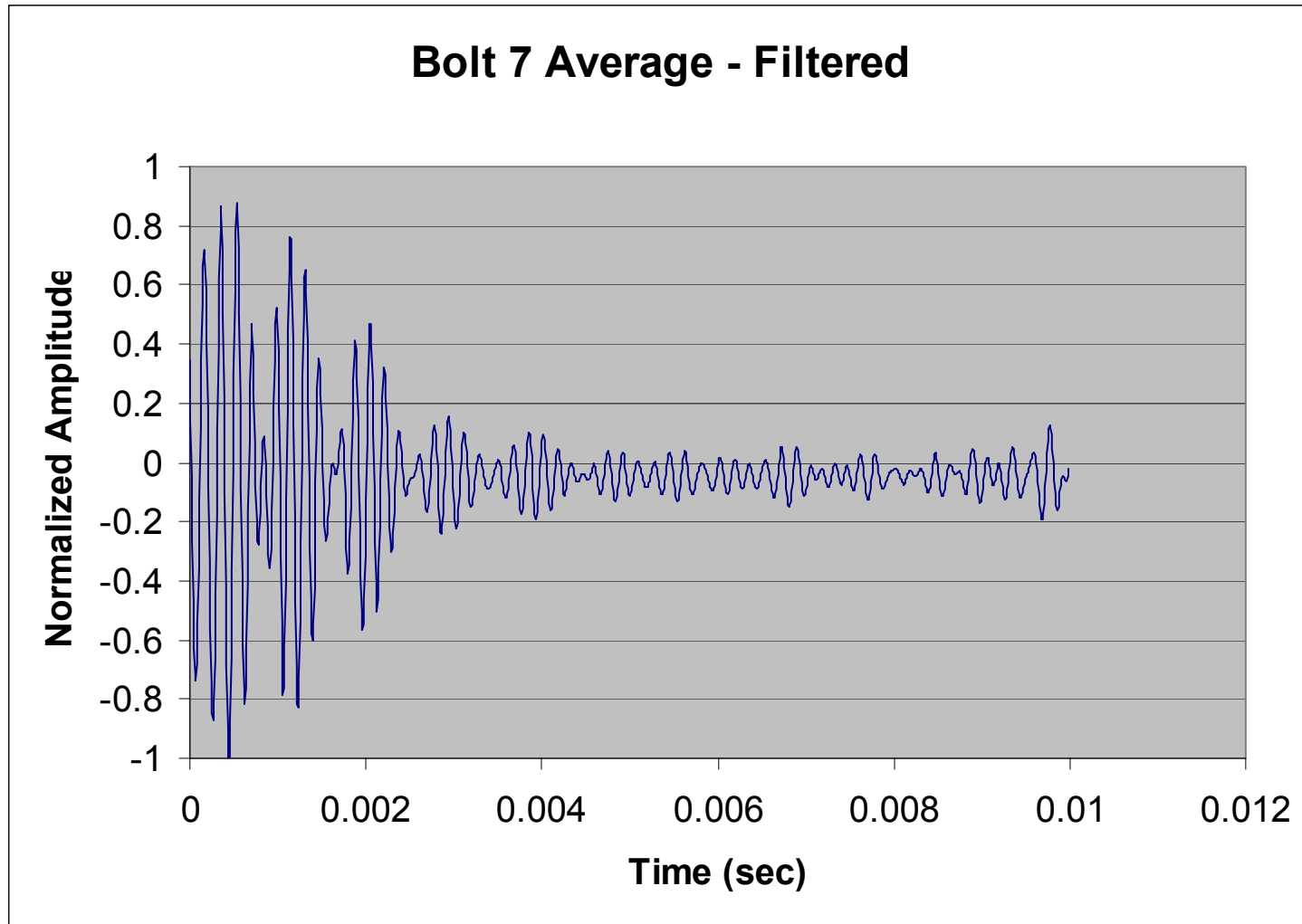


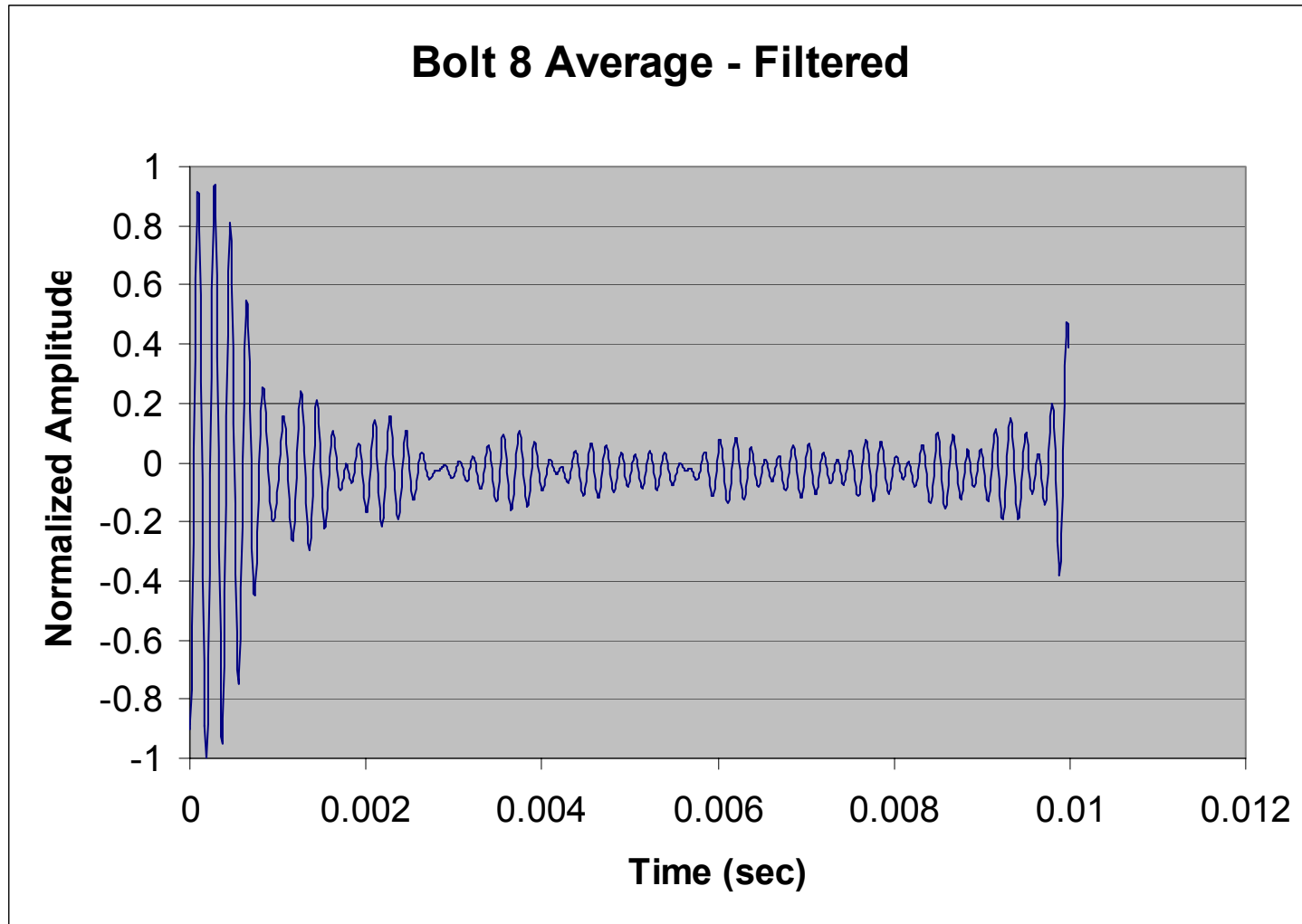


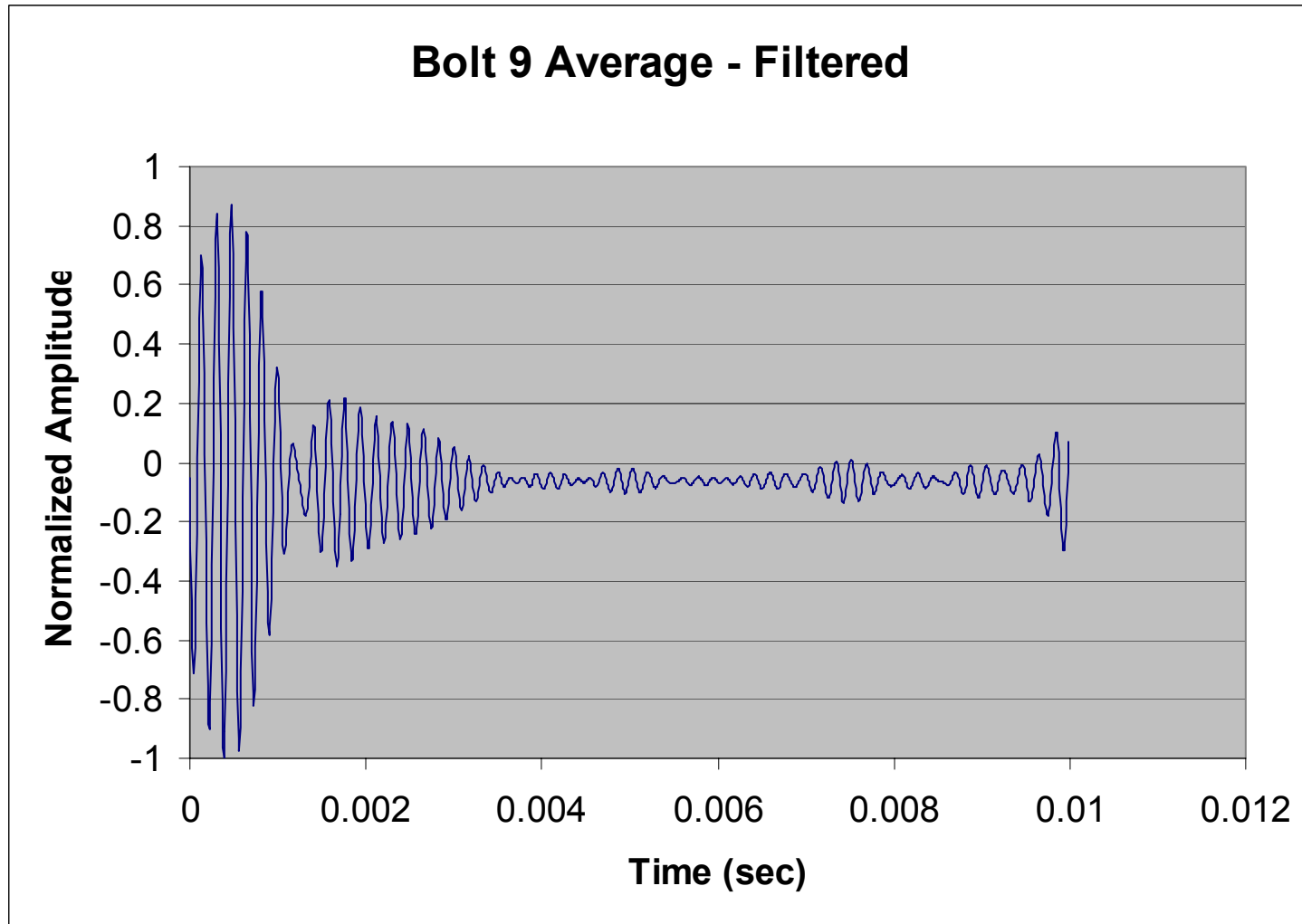


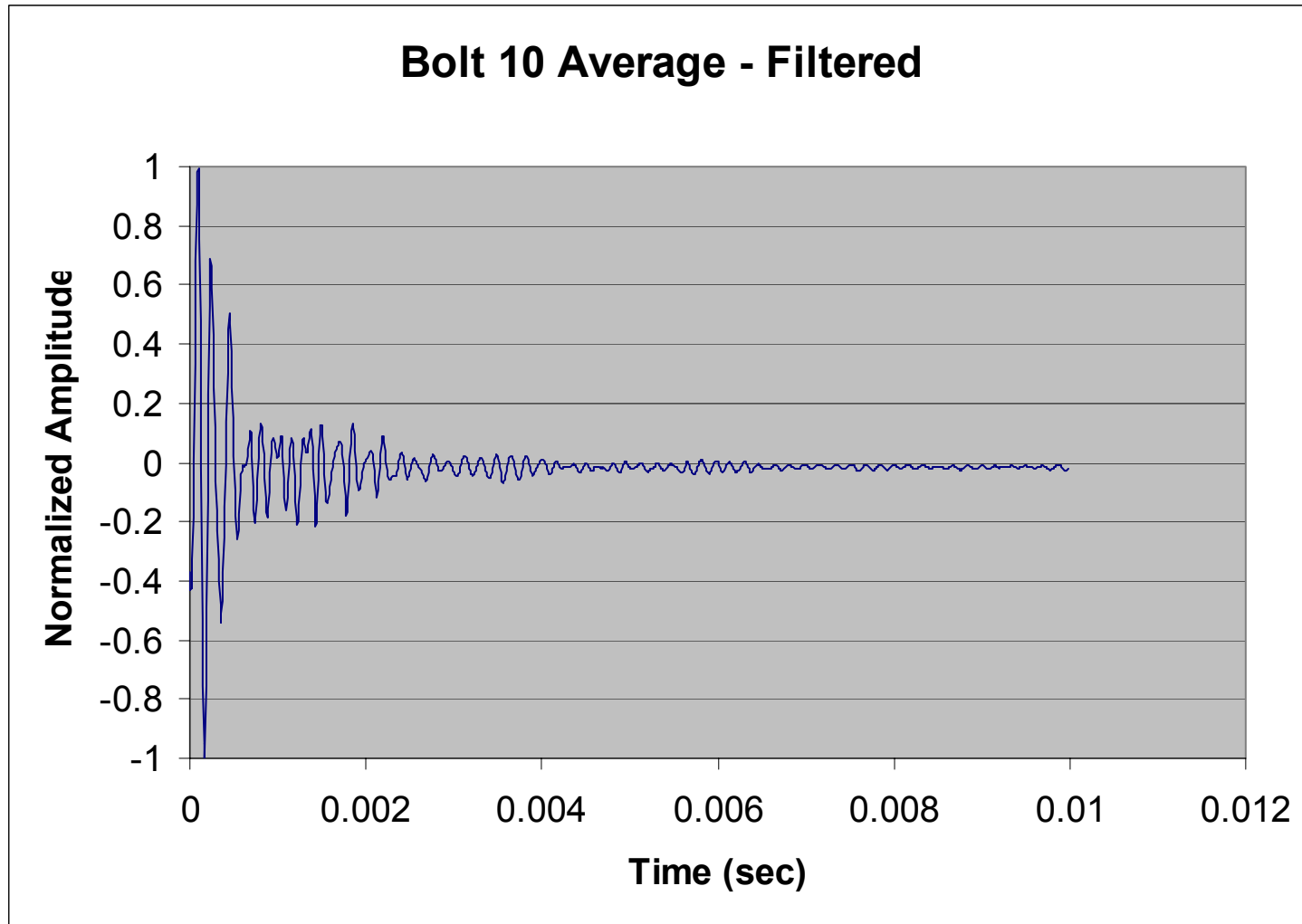


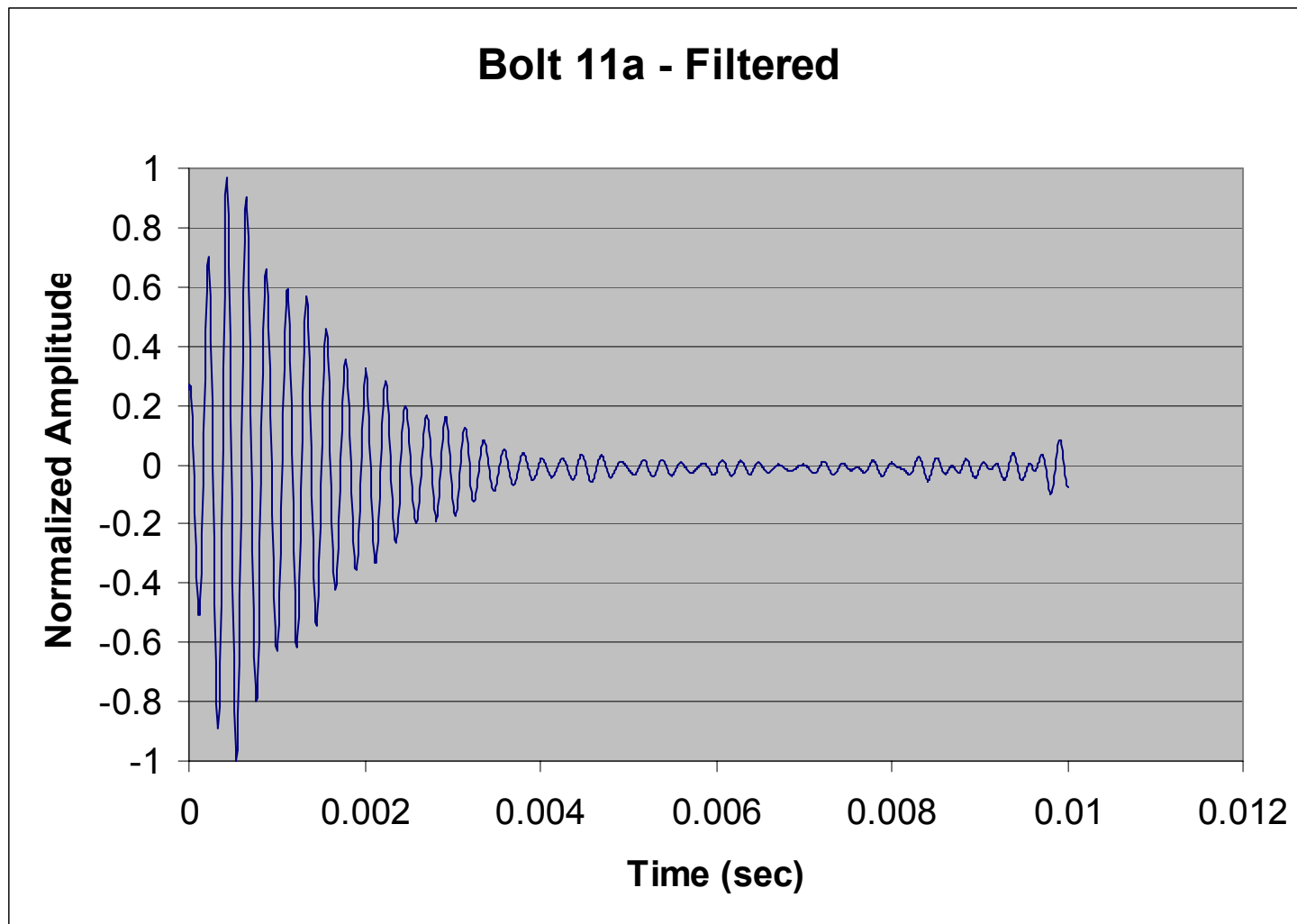




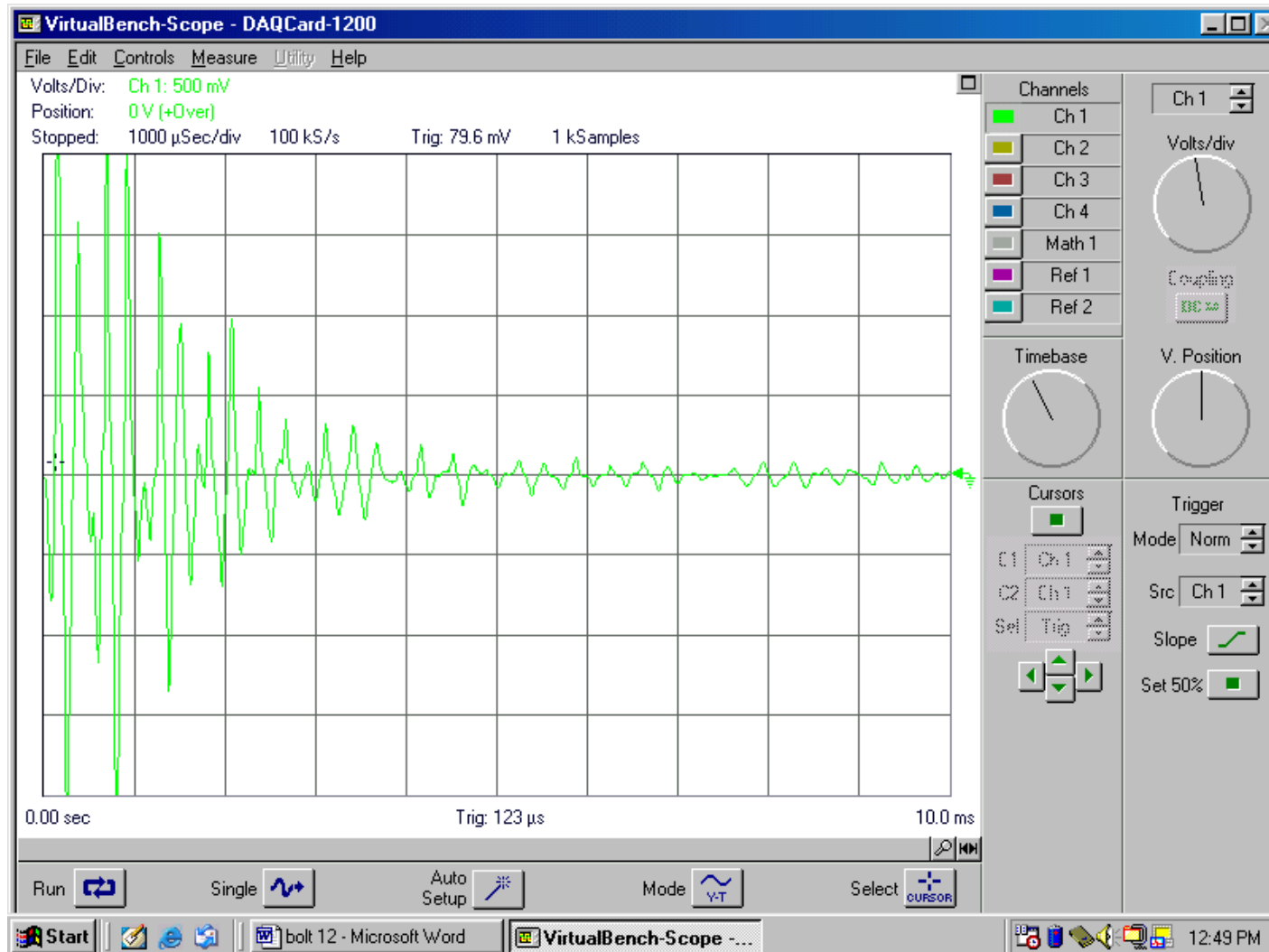


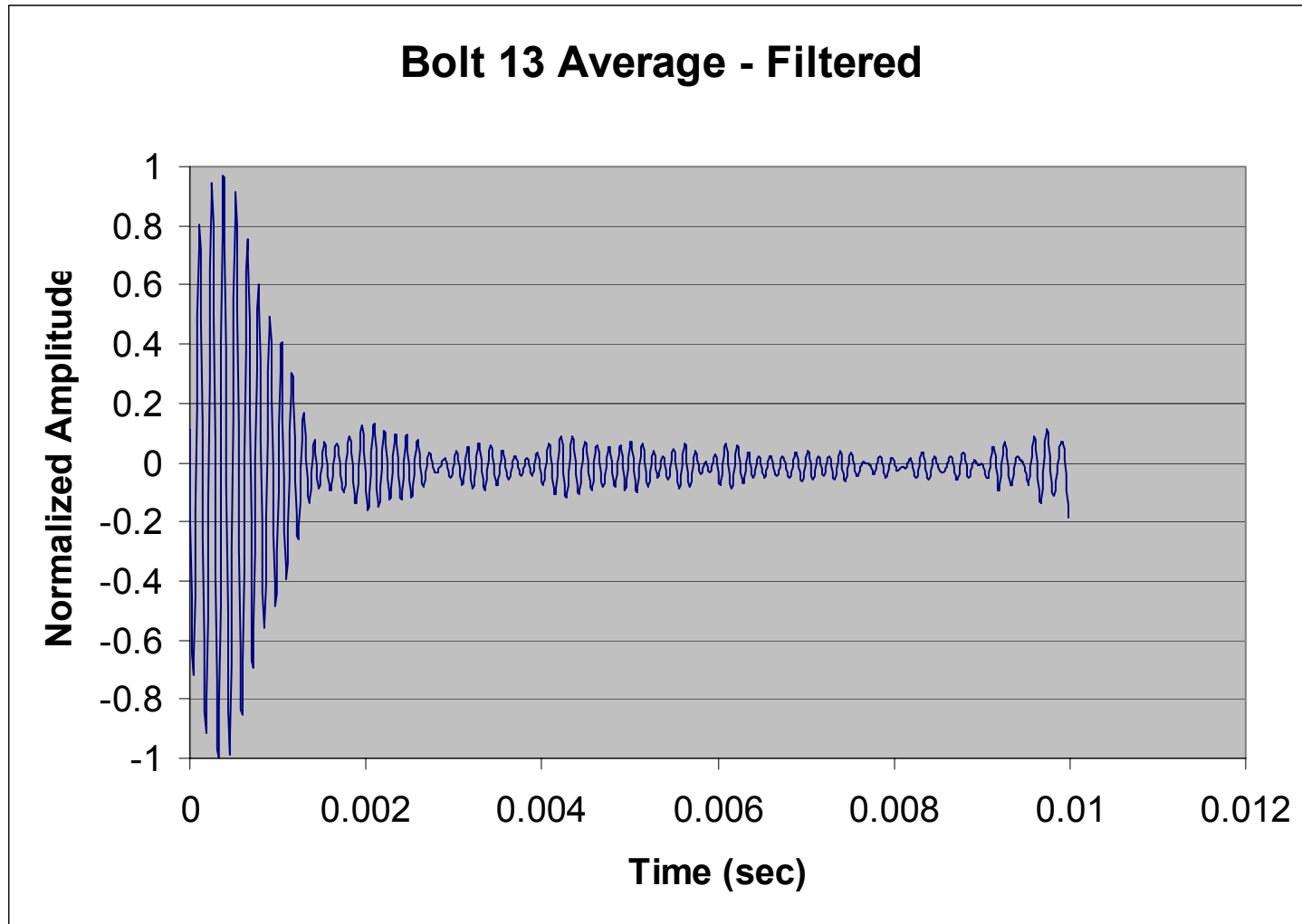


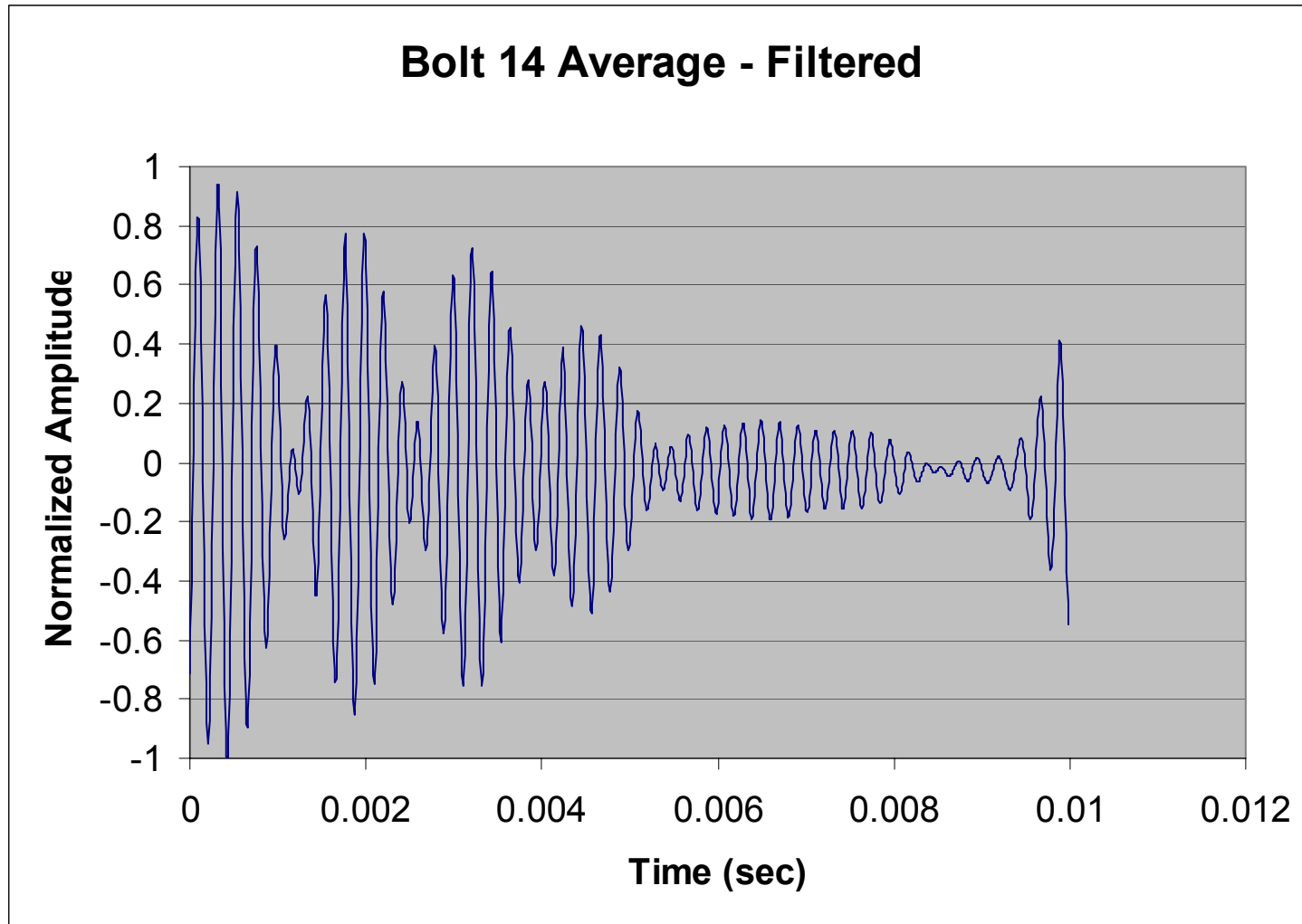


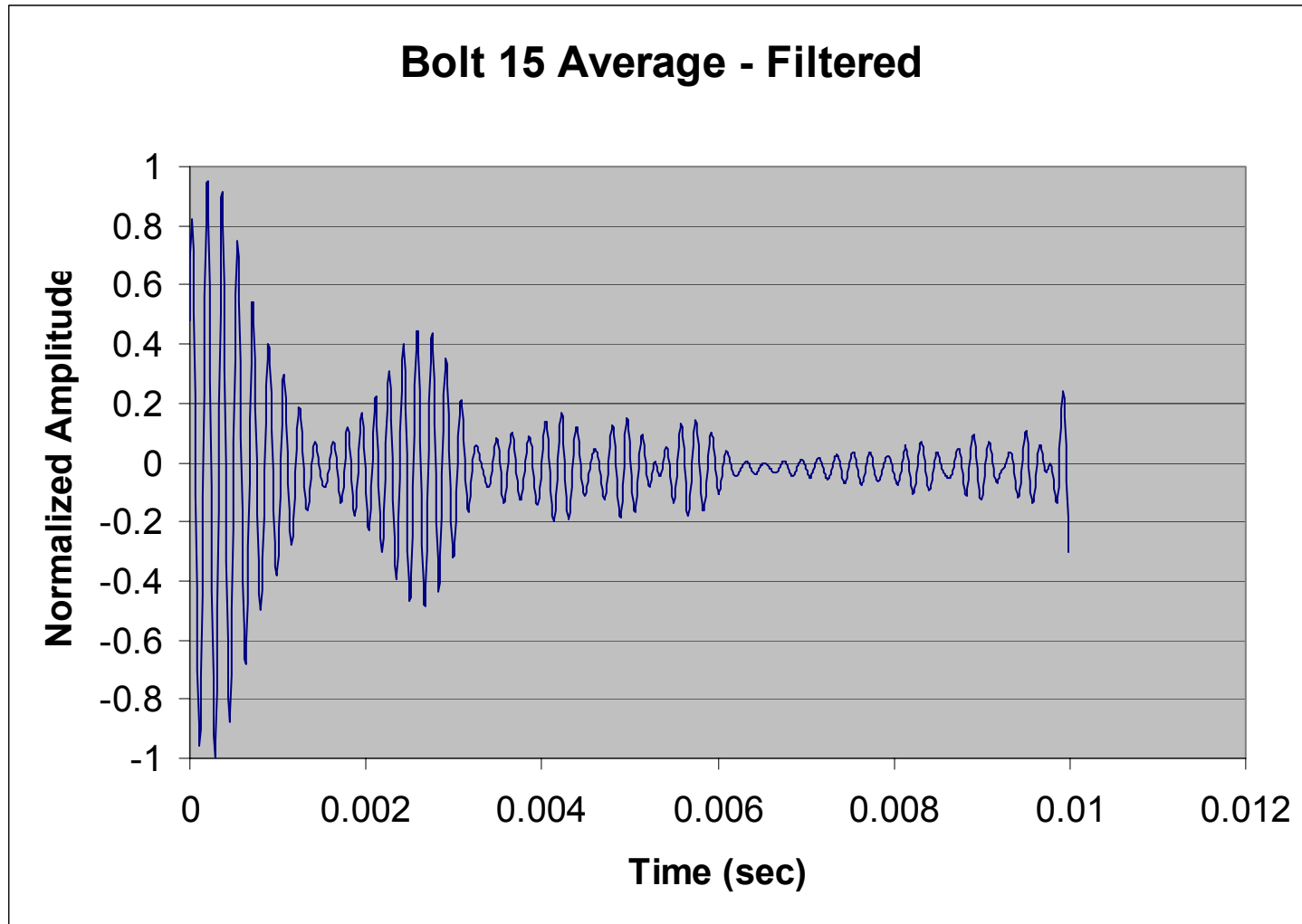


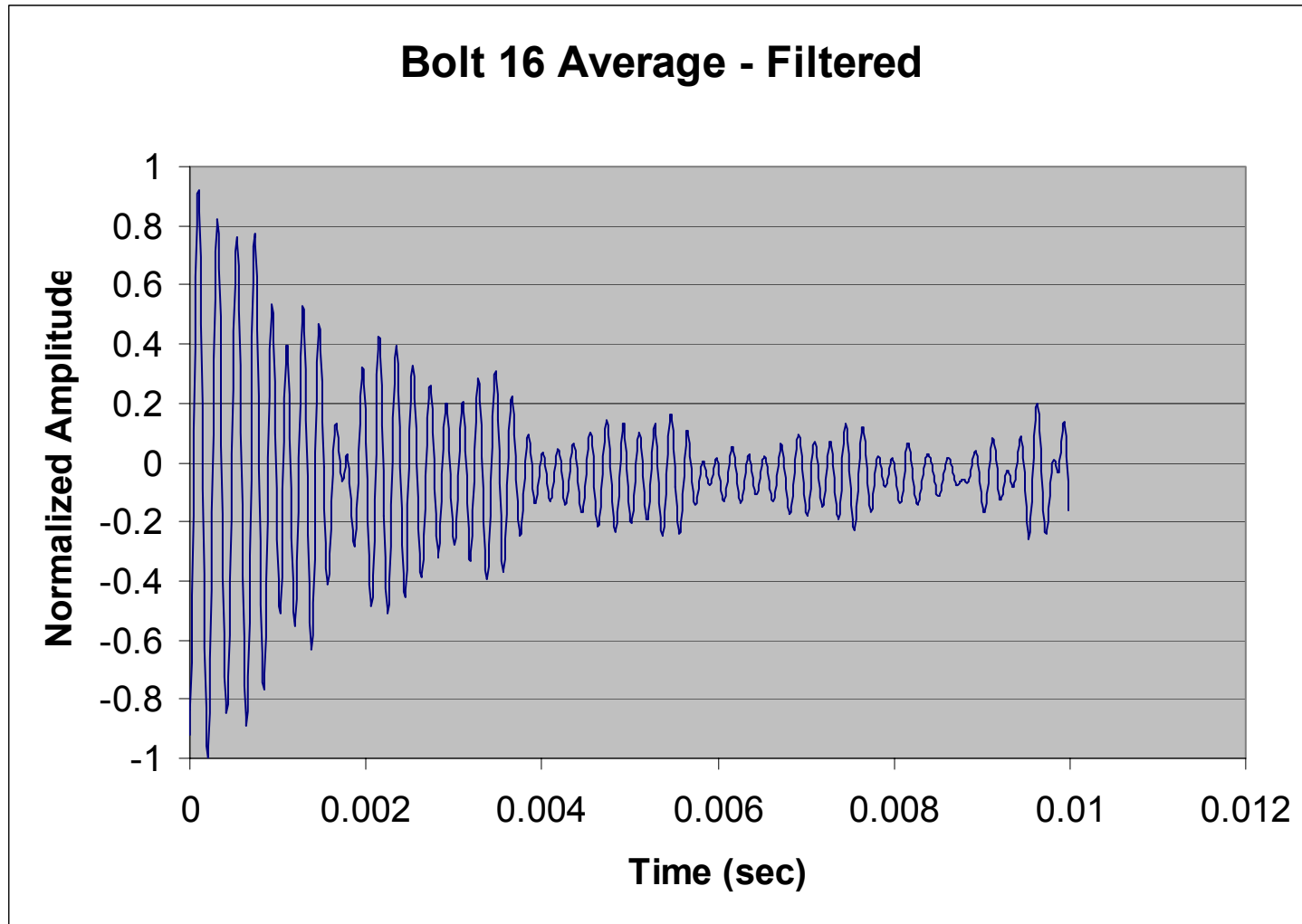
BARRON MOUNTAIN BOLT #12- TIME HISTORY

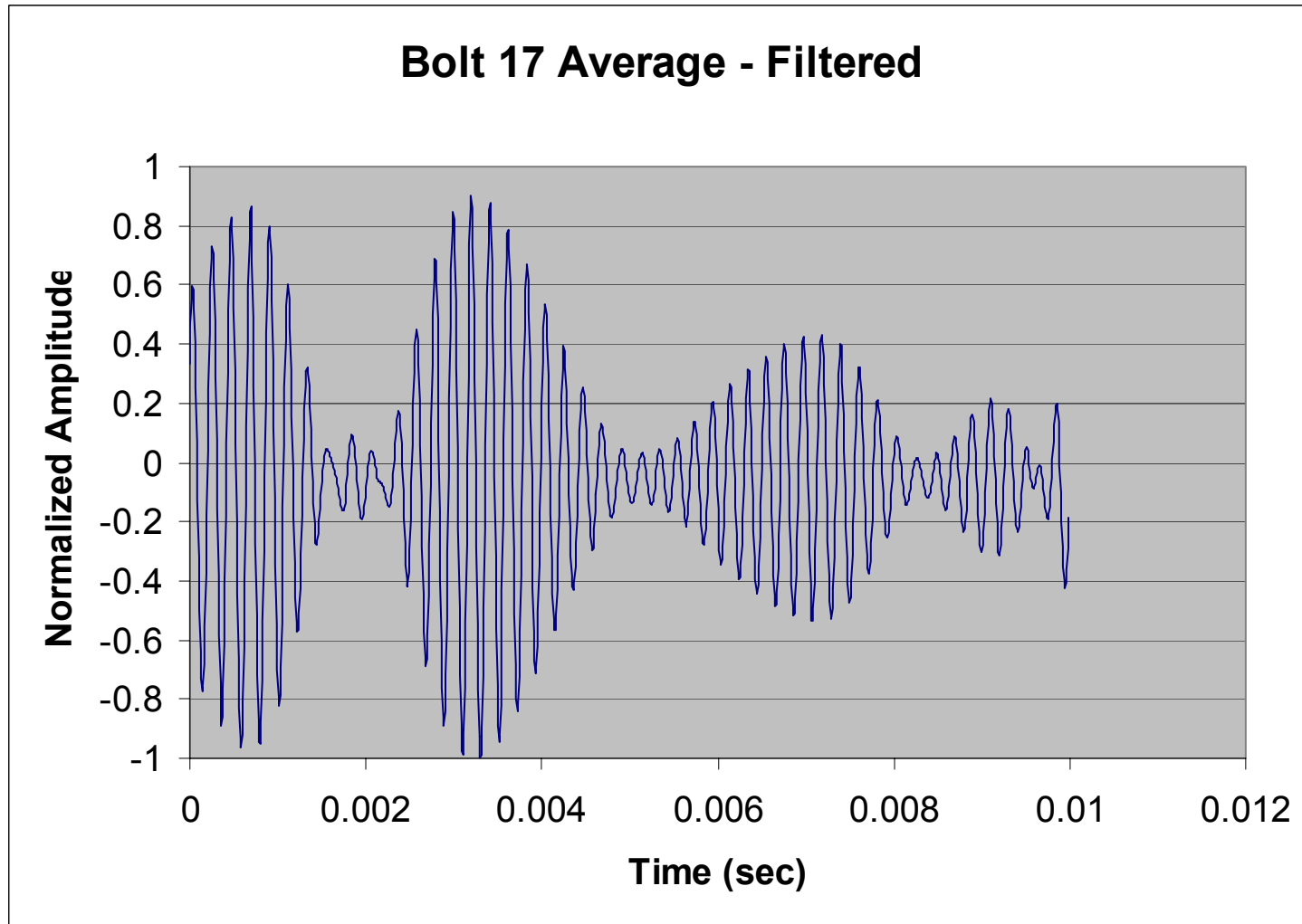


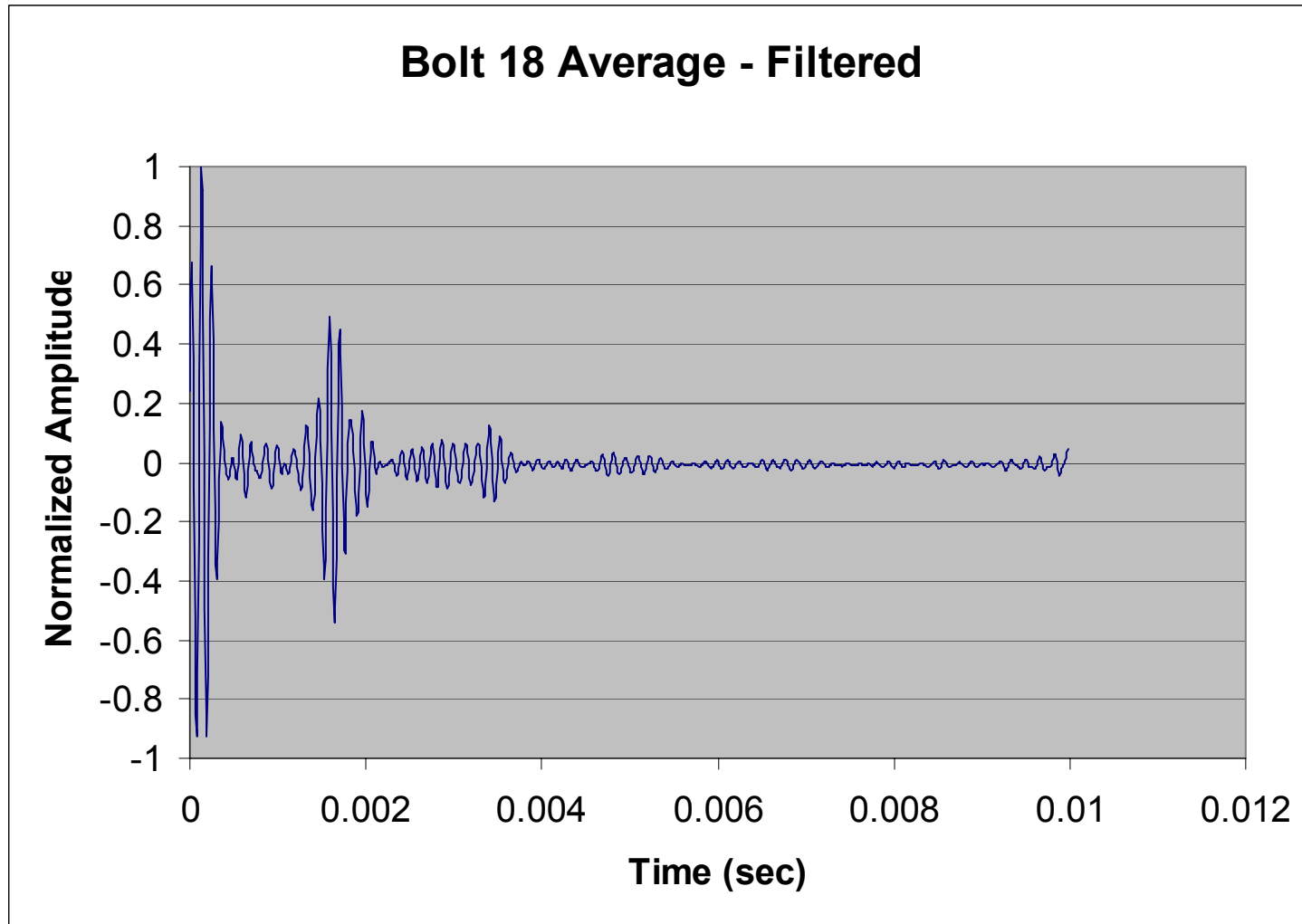


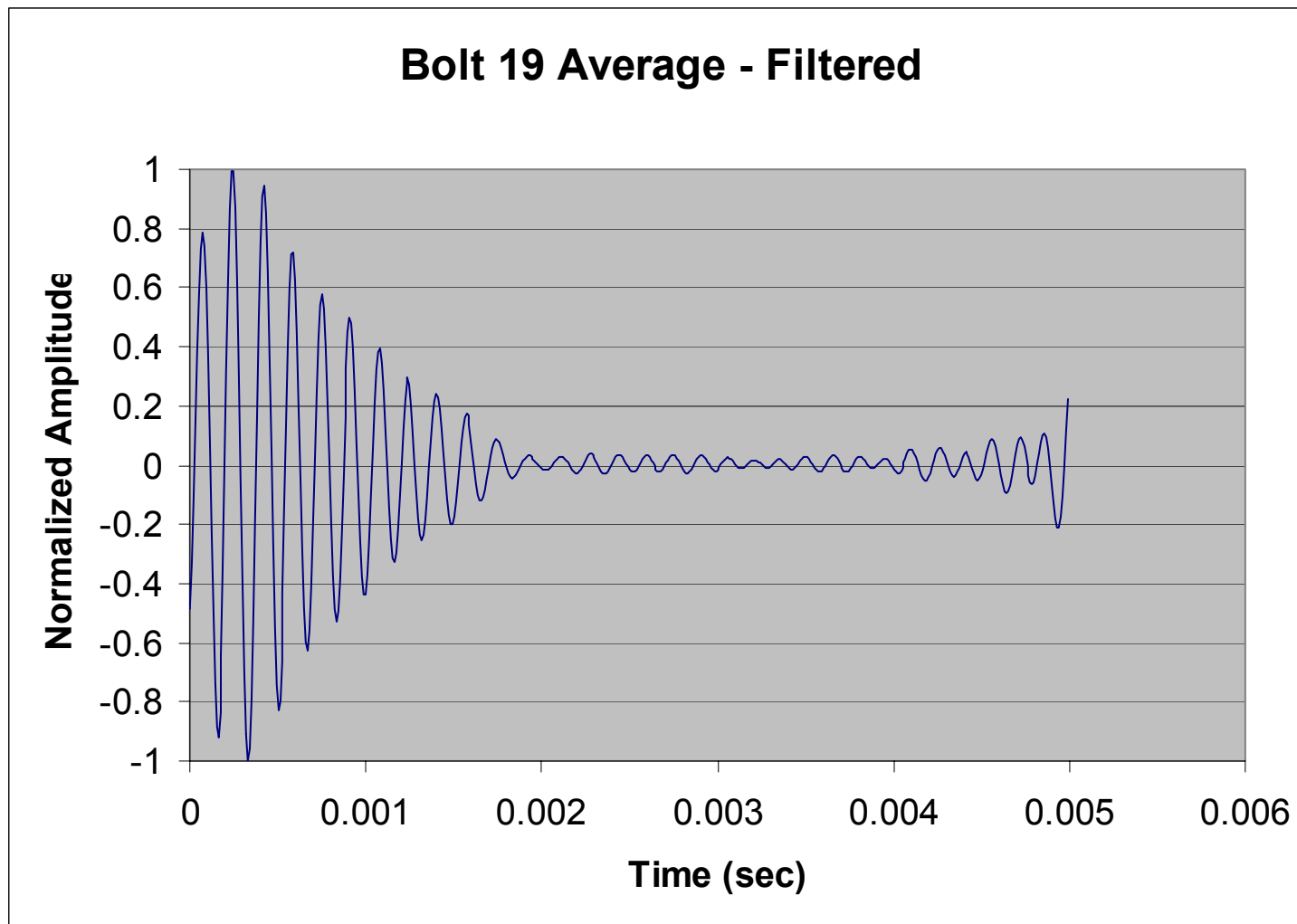


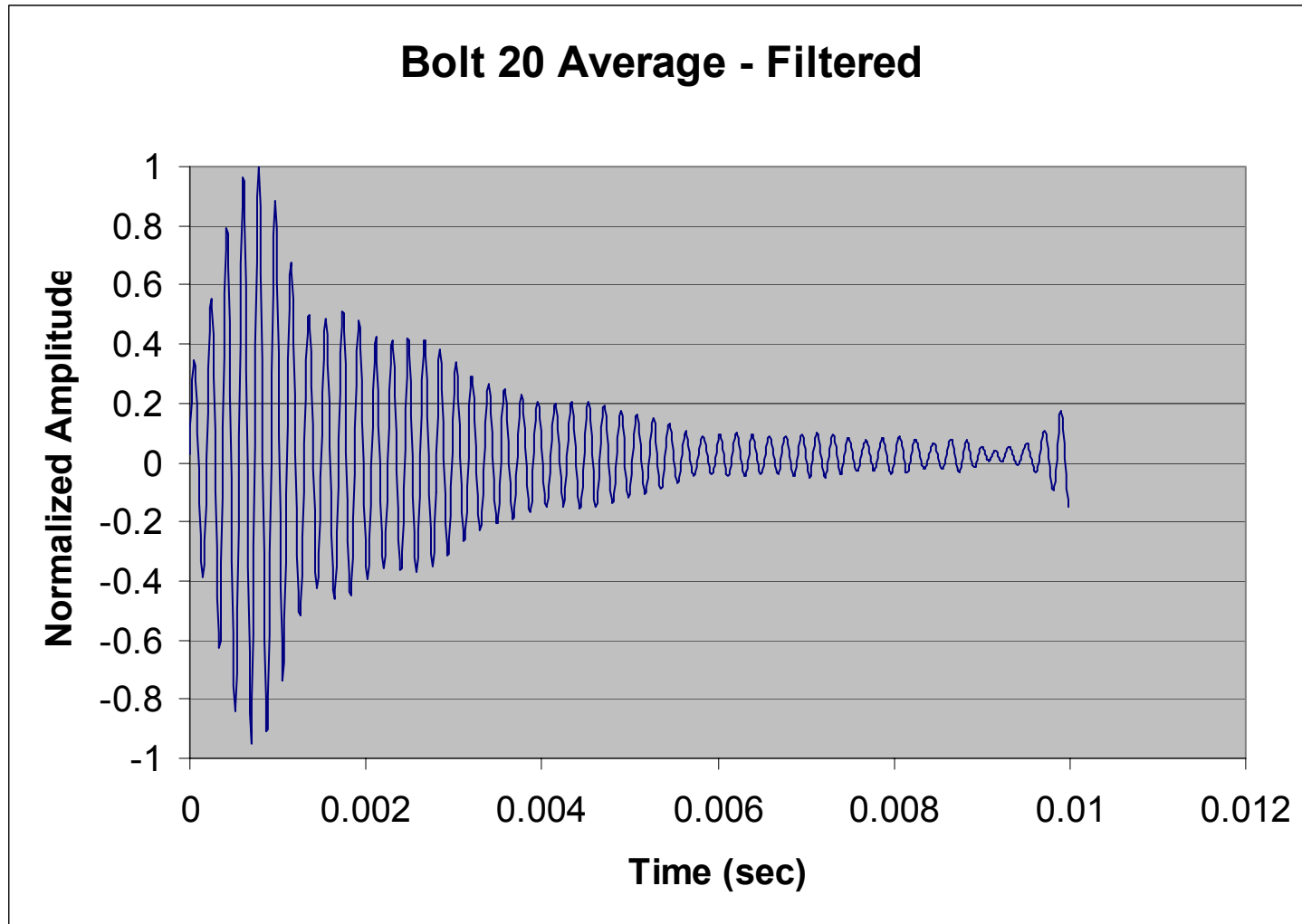


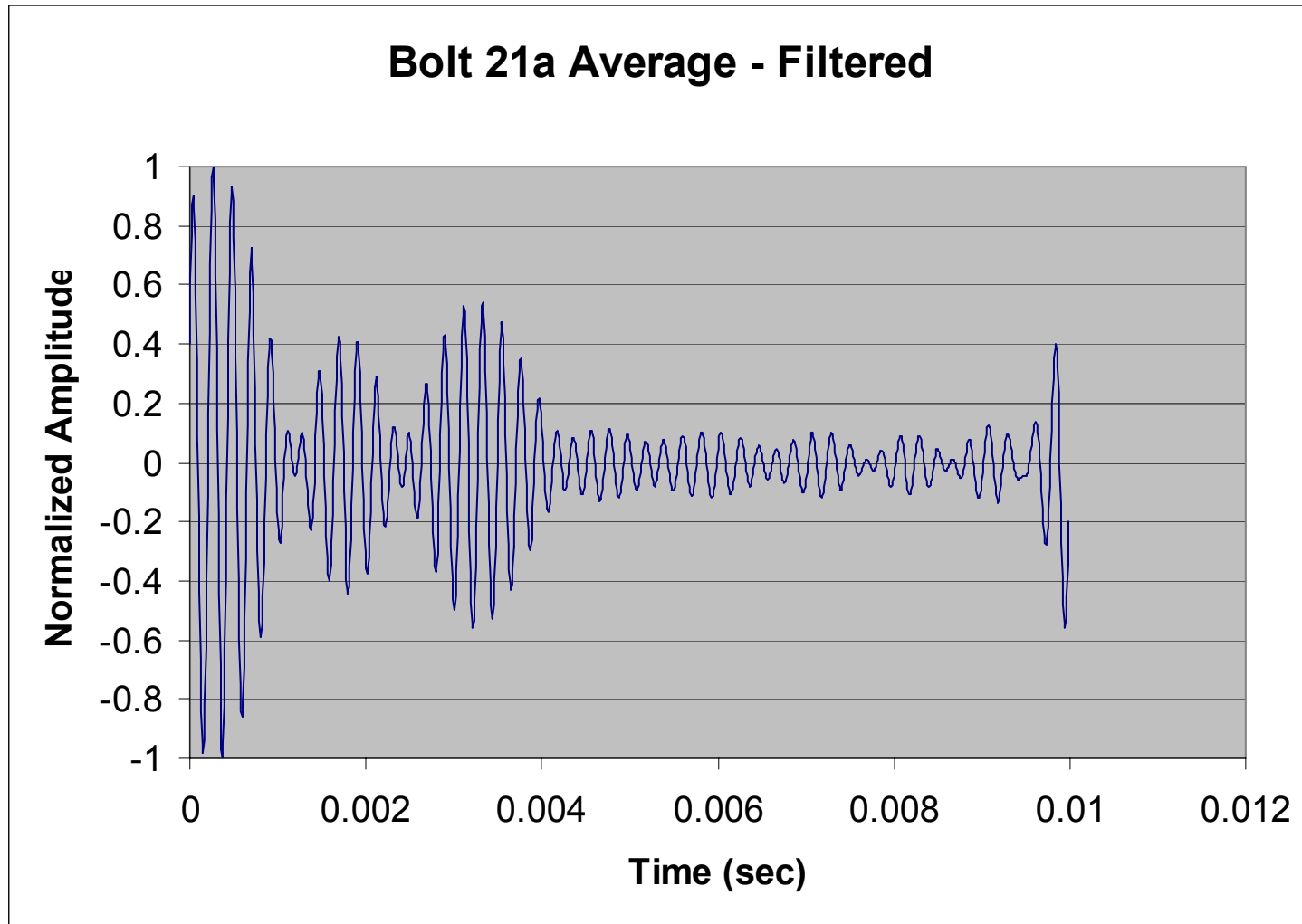




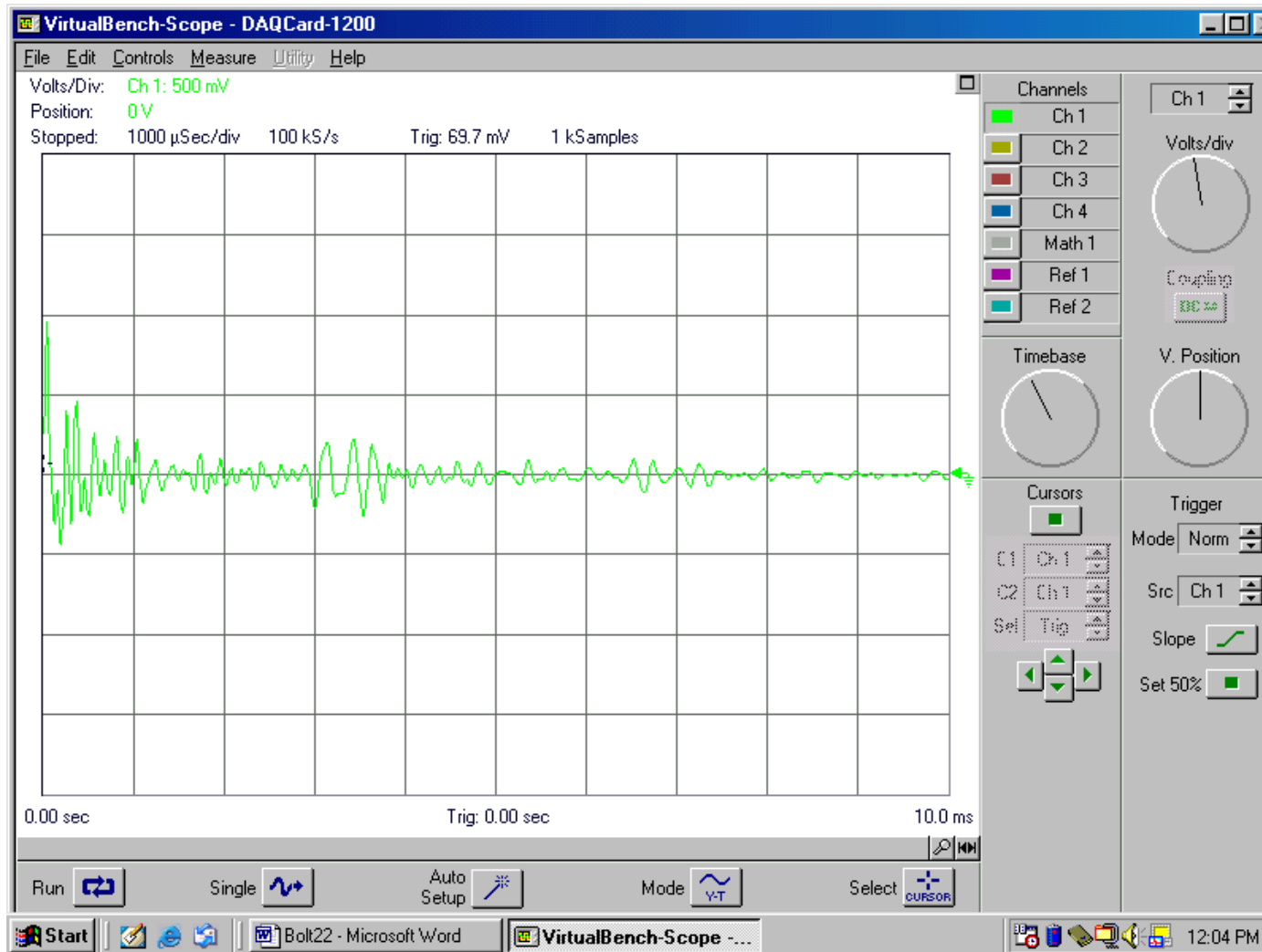








BARRON MOUNTAIN BOLT #22- TIME HISTORY



APPENDIX VIII

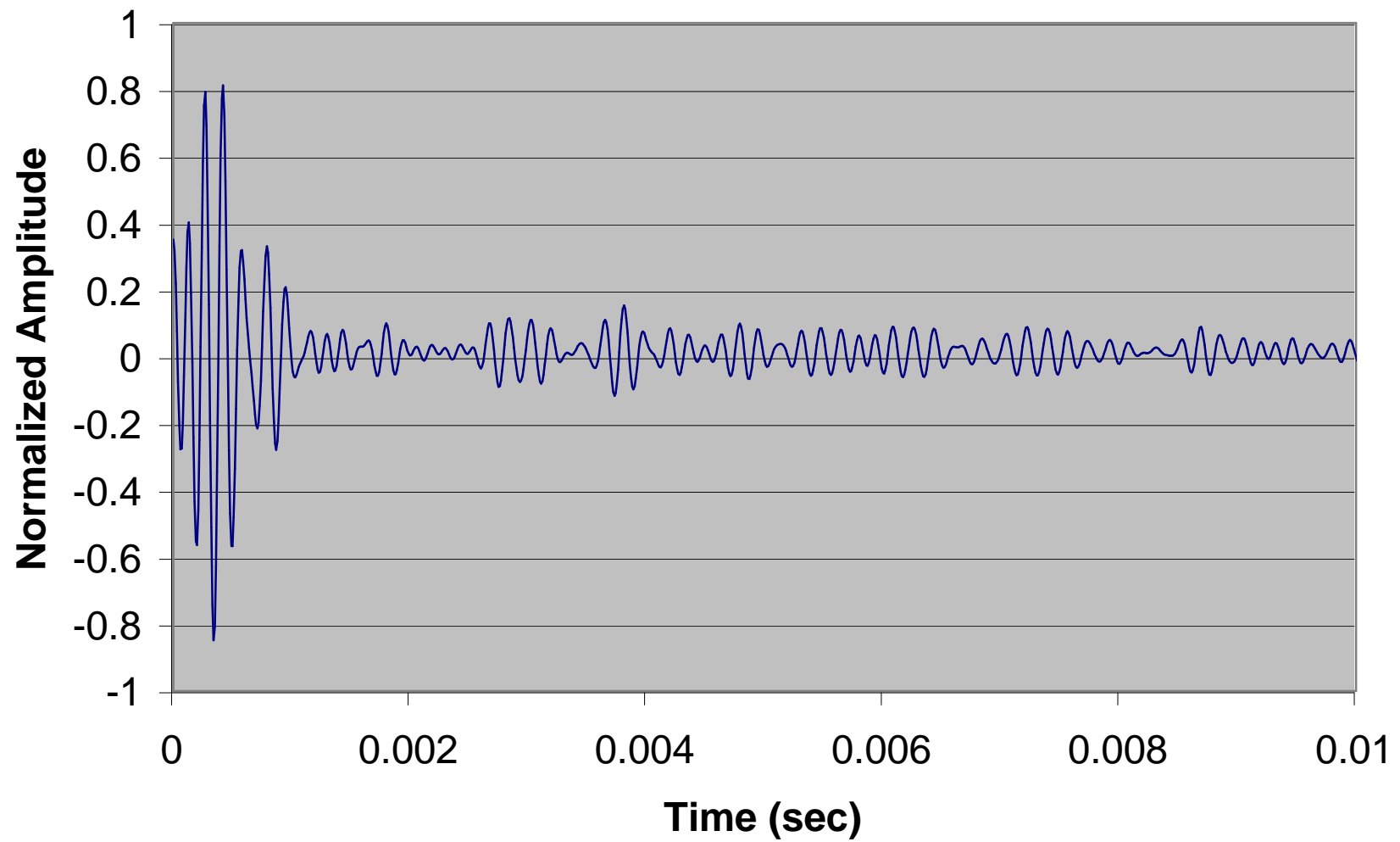
ROCK TENDONS

IMPACT ACCELERATION TIME HISTORIES

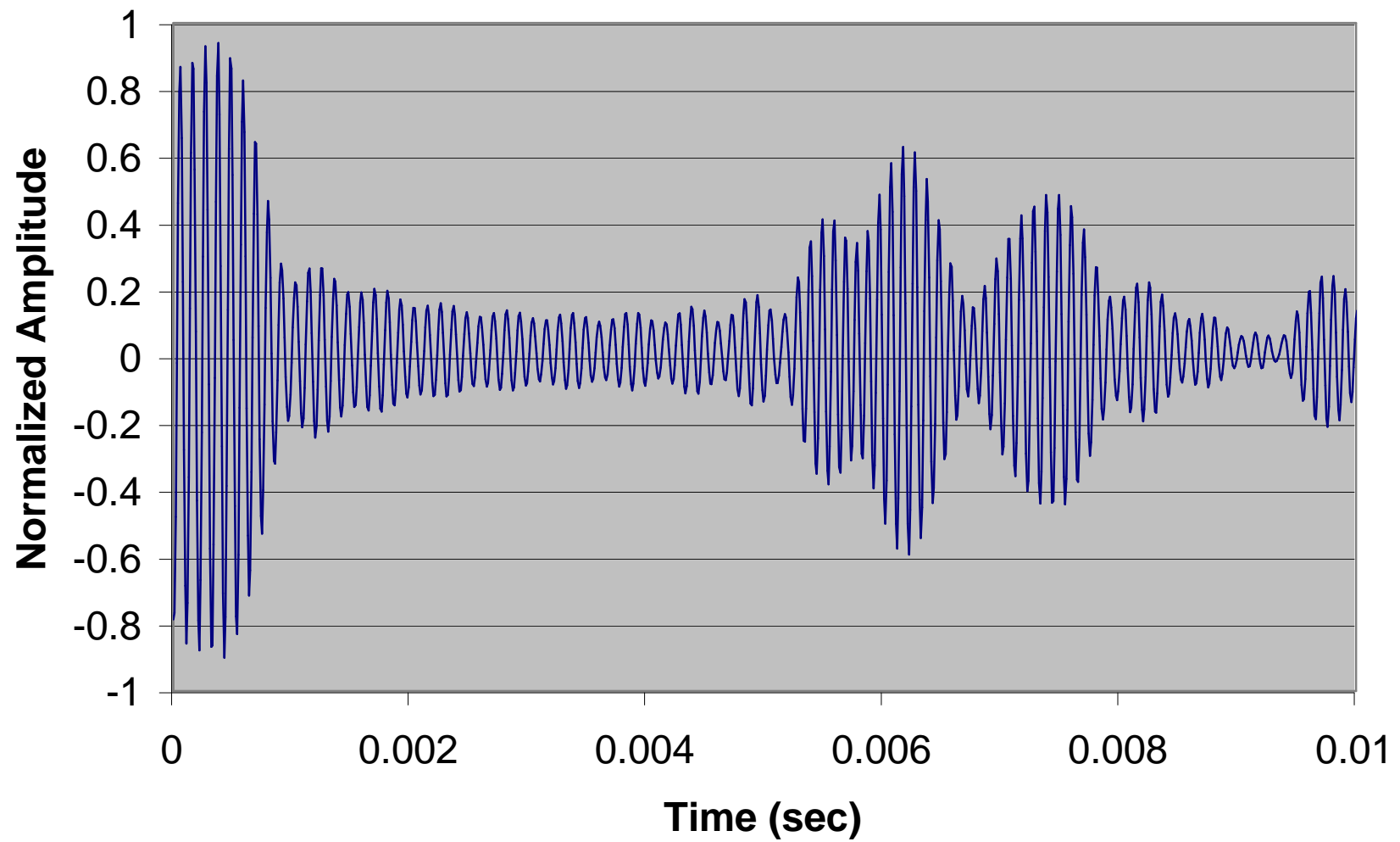
Table VIII-1. Observed Reflections from Impact Test on Tendon Reinforcements.

Test Tendon #	Relative Signal Attenuation	Observed L_1 (ft)	Observed L_2 (ft)
1-1	Strong	8	55
1-2	Weak	~	51
1-3	Weak	27	58
1-4	Strong	8	~
2-1	Strong	~	57
2-2	Strong	5	~
2-3	Strong	5	63
2-4	Strong	10	~
3-1	Weak	17	~
3-2	Strong	8	62
3-3	Strong	6	~
3-4	Strong	6	64
4-1	Strong	9	~
4-2	Strong	8	~
4-3	Strong	4	~
4-4	Strong	3	~
5-1	Strong	11	~
5-2	Weak	8	~
5-3	Strong	6	~
5-4	Strong	4	~

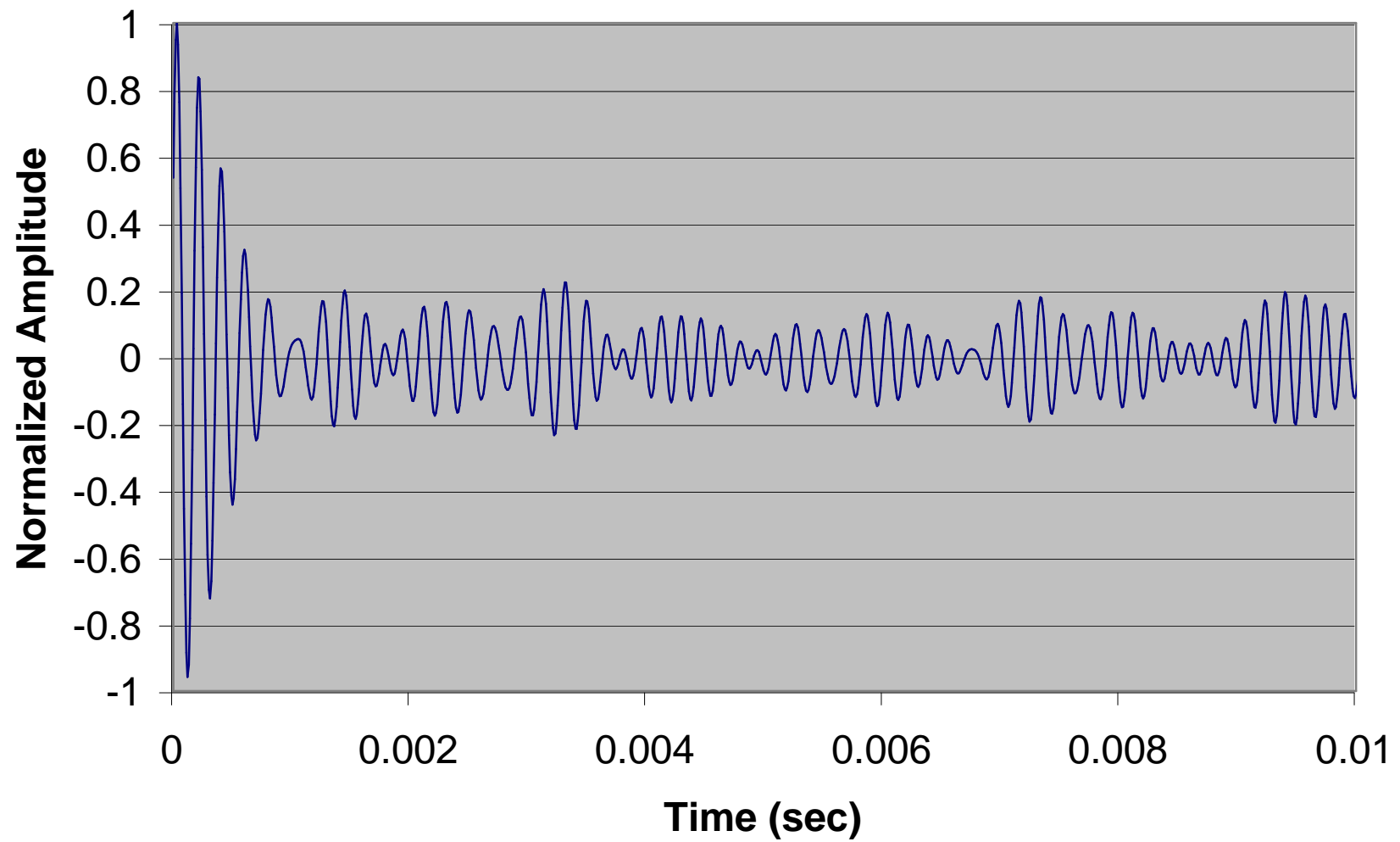
Tendon 1-1 Average - Filtered



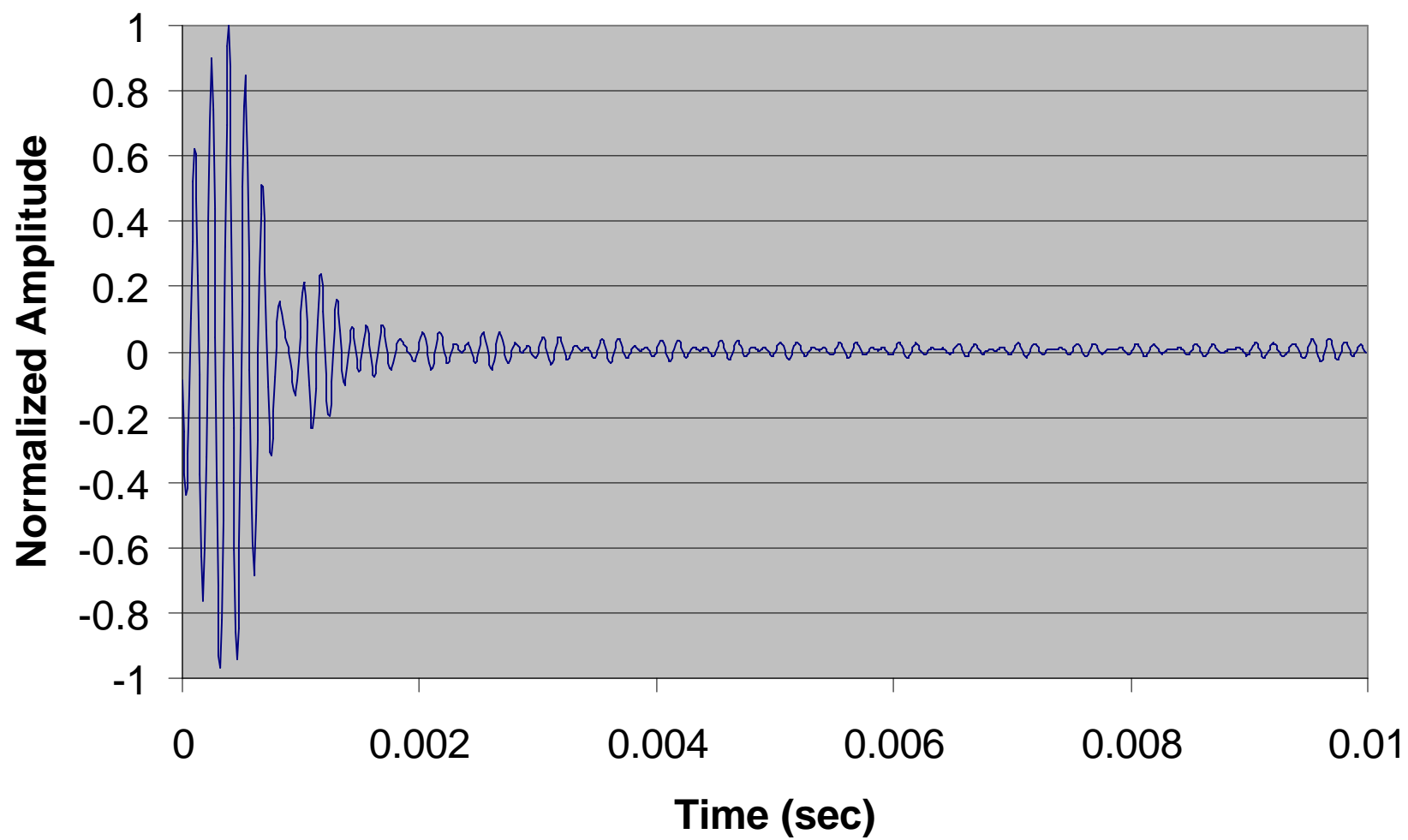
Tendon 1-2 Average - Filtered



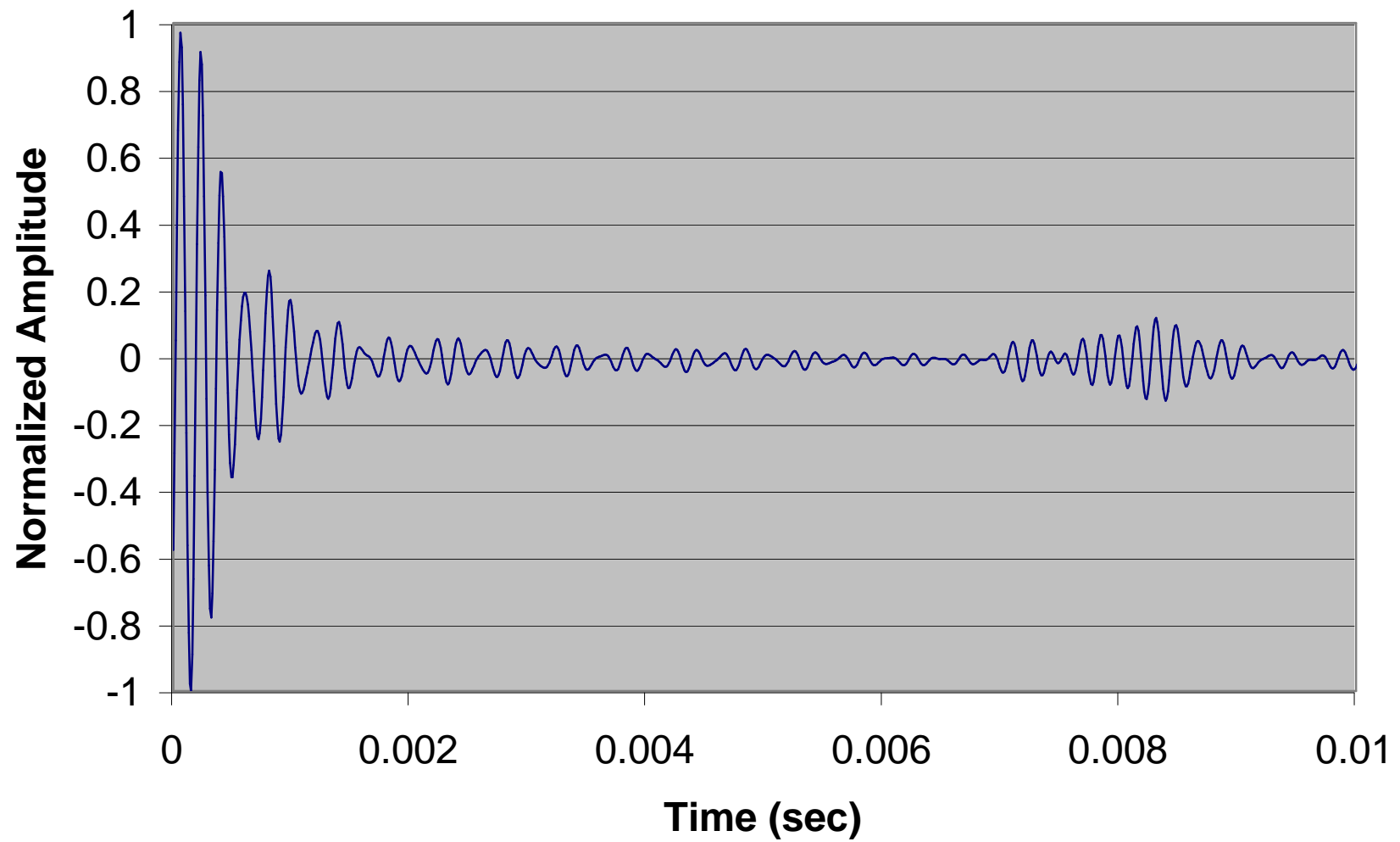
Tendon 1-3 Average - Filtered



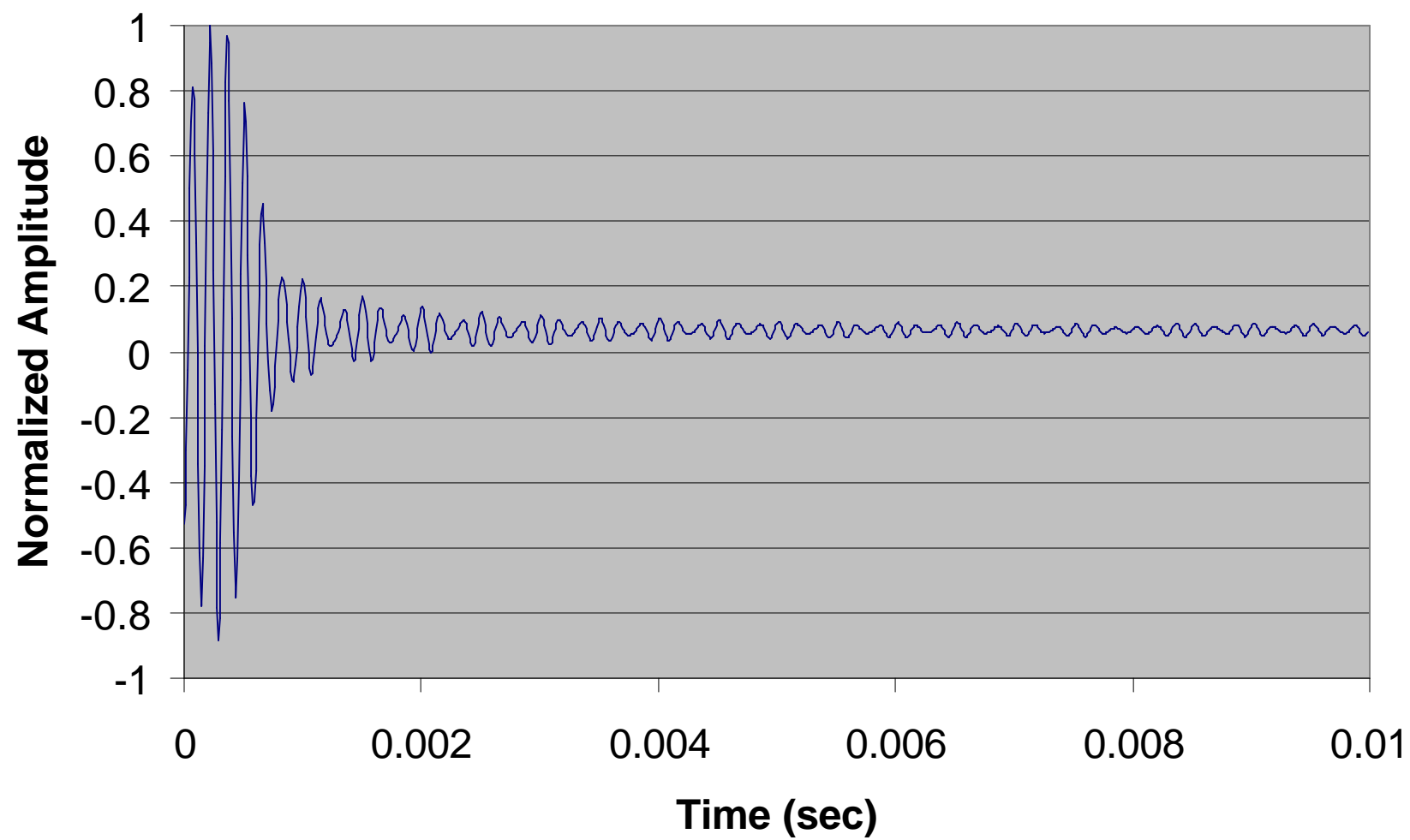
Tendon 1-4 Average - Filtered



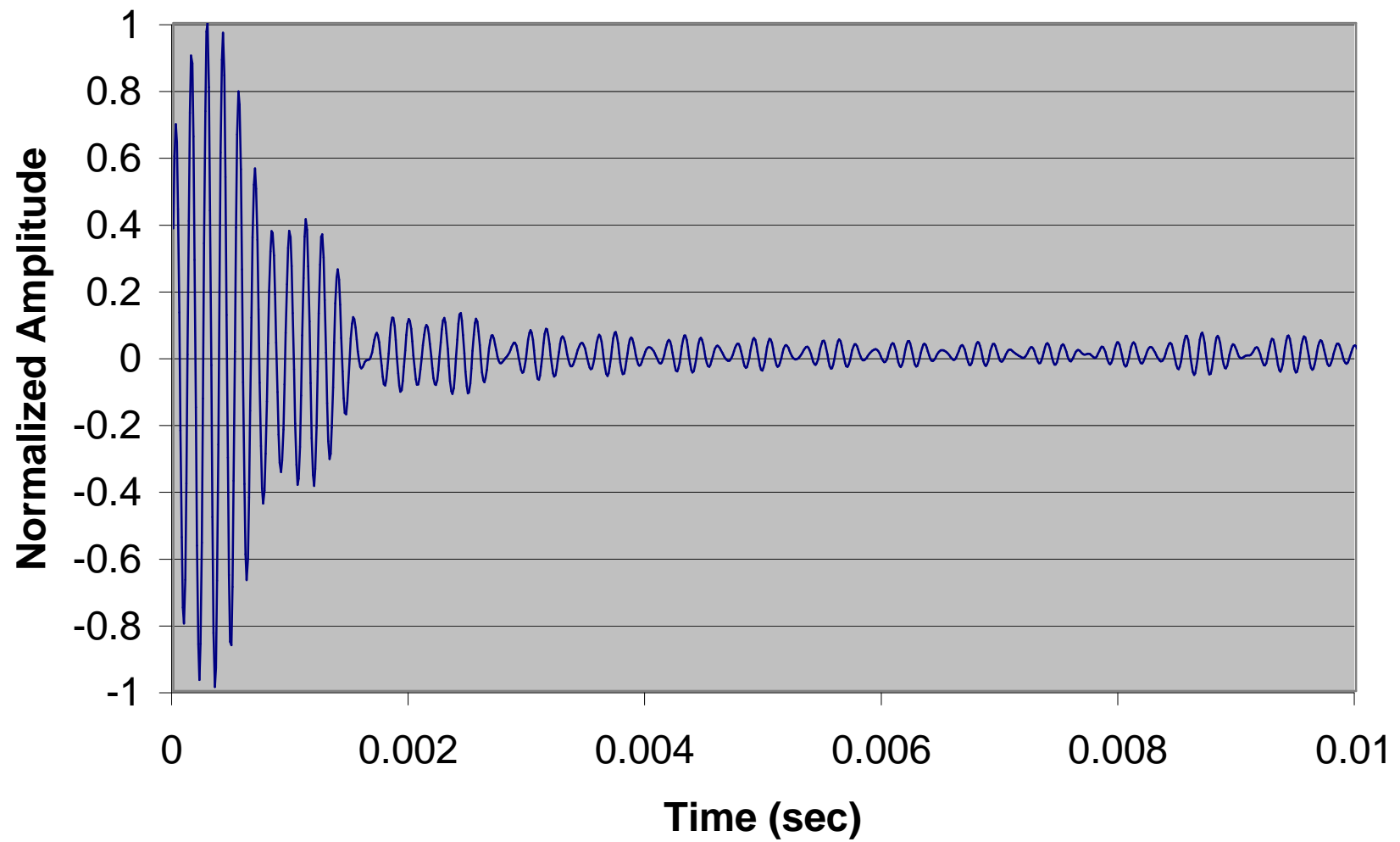
Tendon 2-1 Average - Filtered



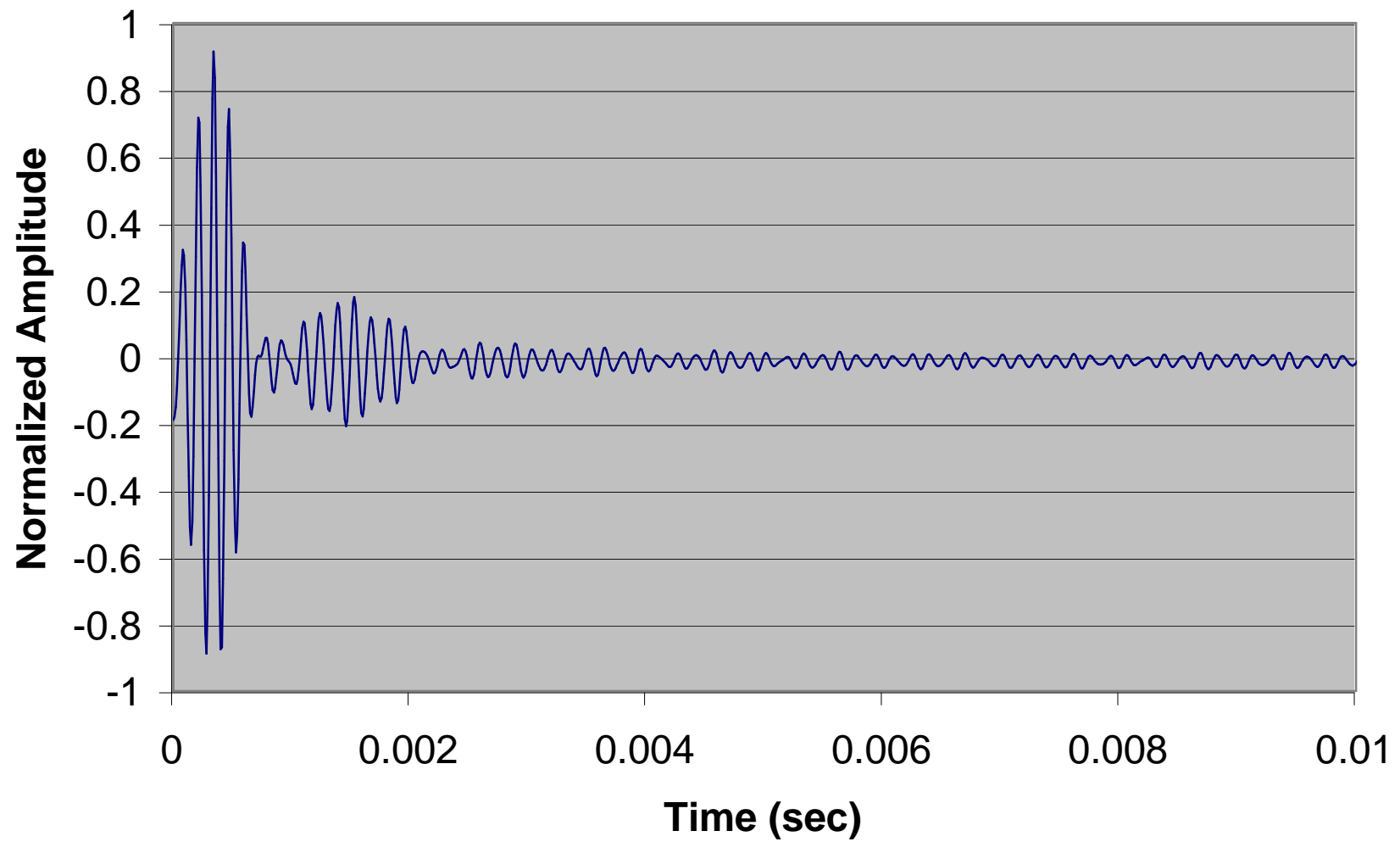
Tendon 2-2 Average - Filtered



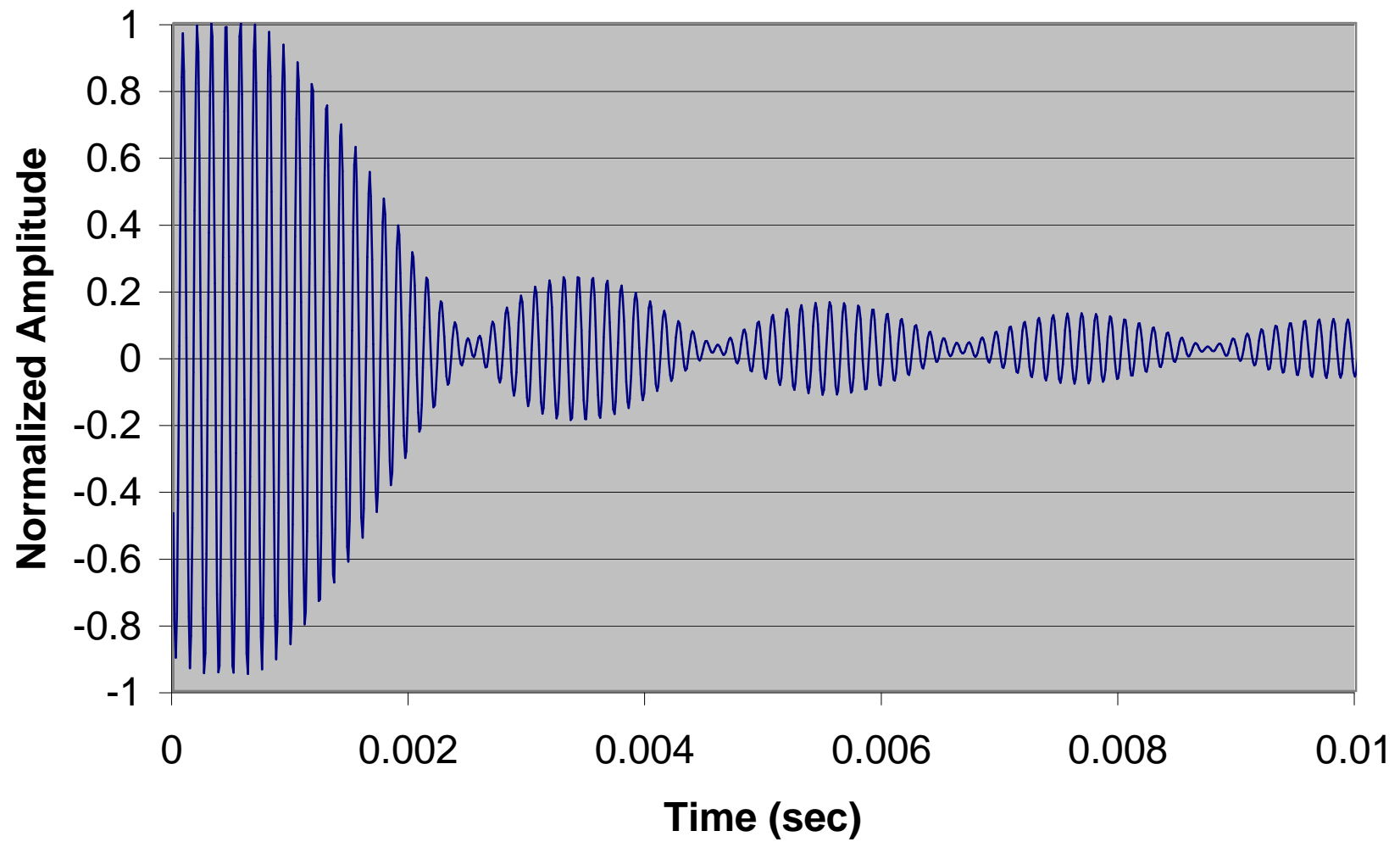
Tendon 2-3 Average - Filtered



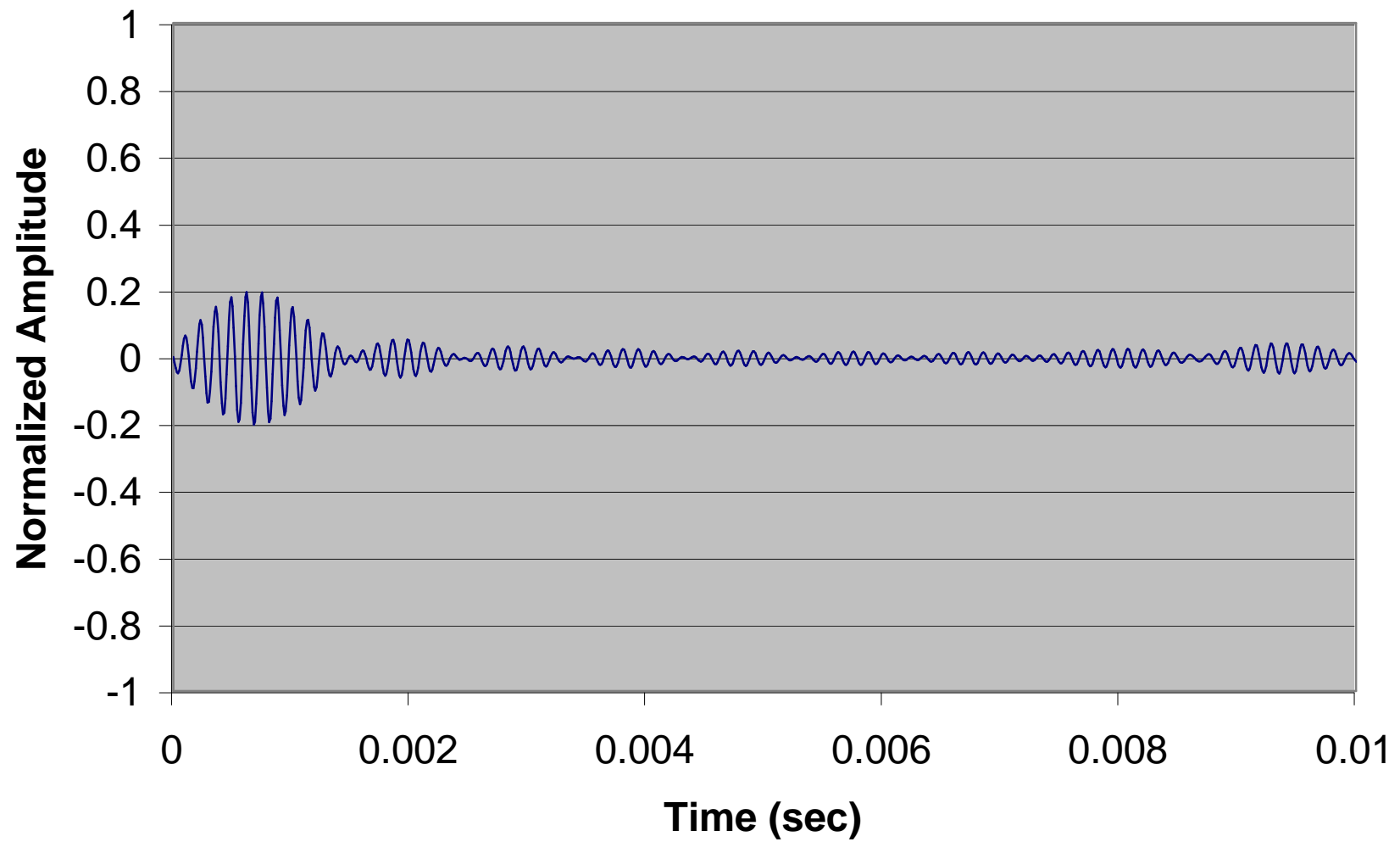
Tendon 2-4 Average - Filtered



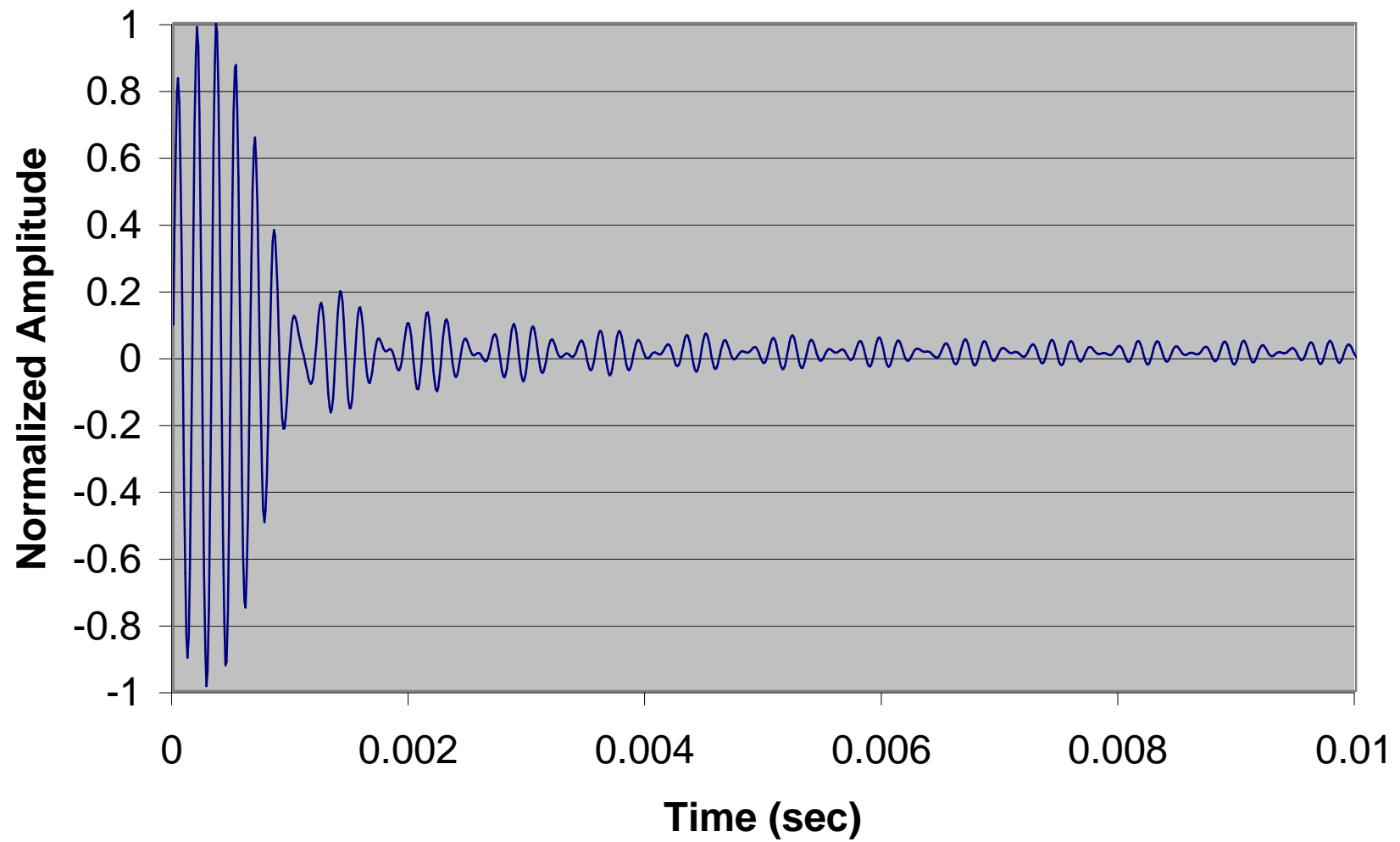
Tendon 3-1 Average - Filtered



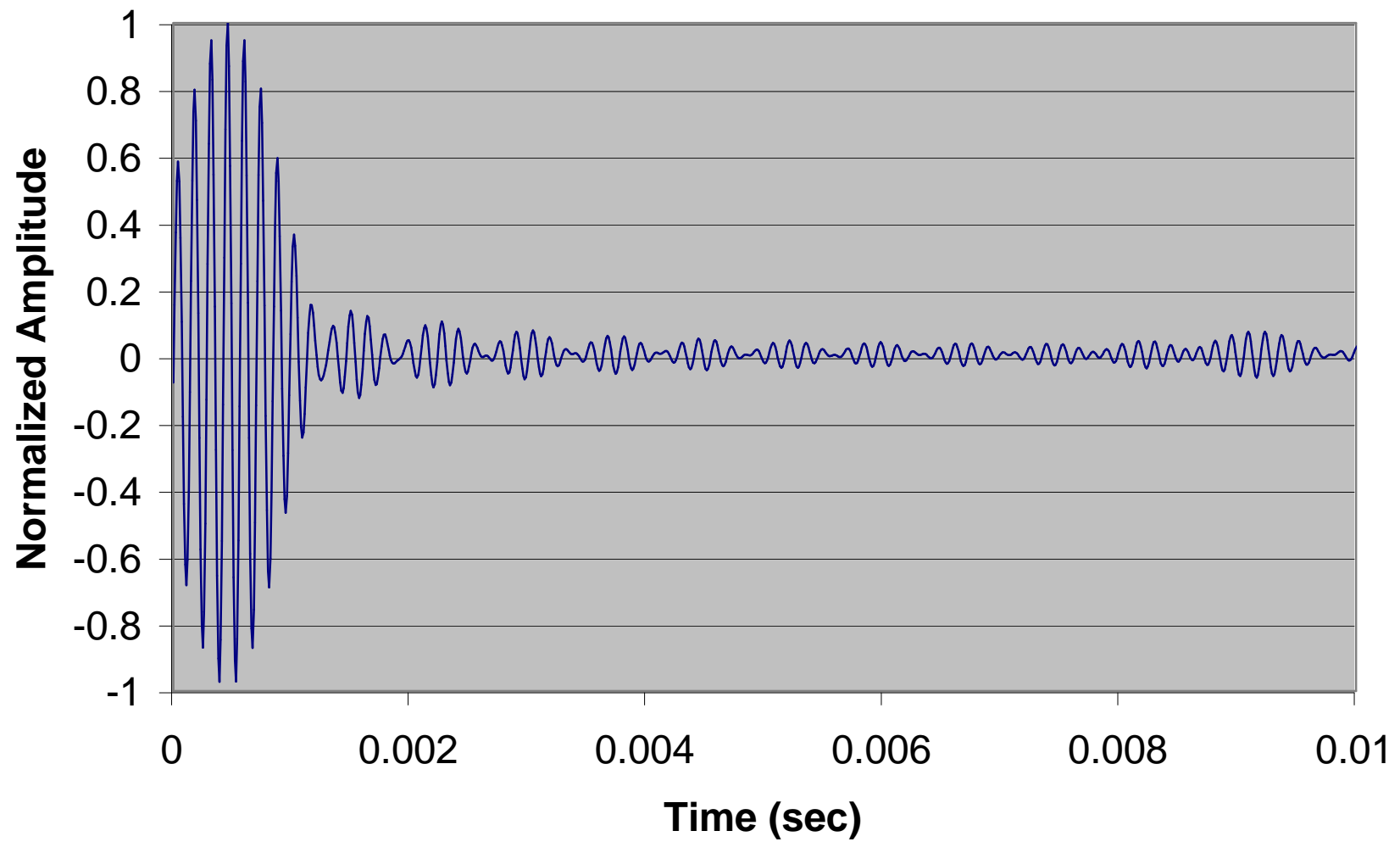
Tendon 3-2 Average - Filtered



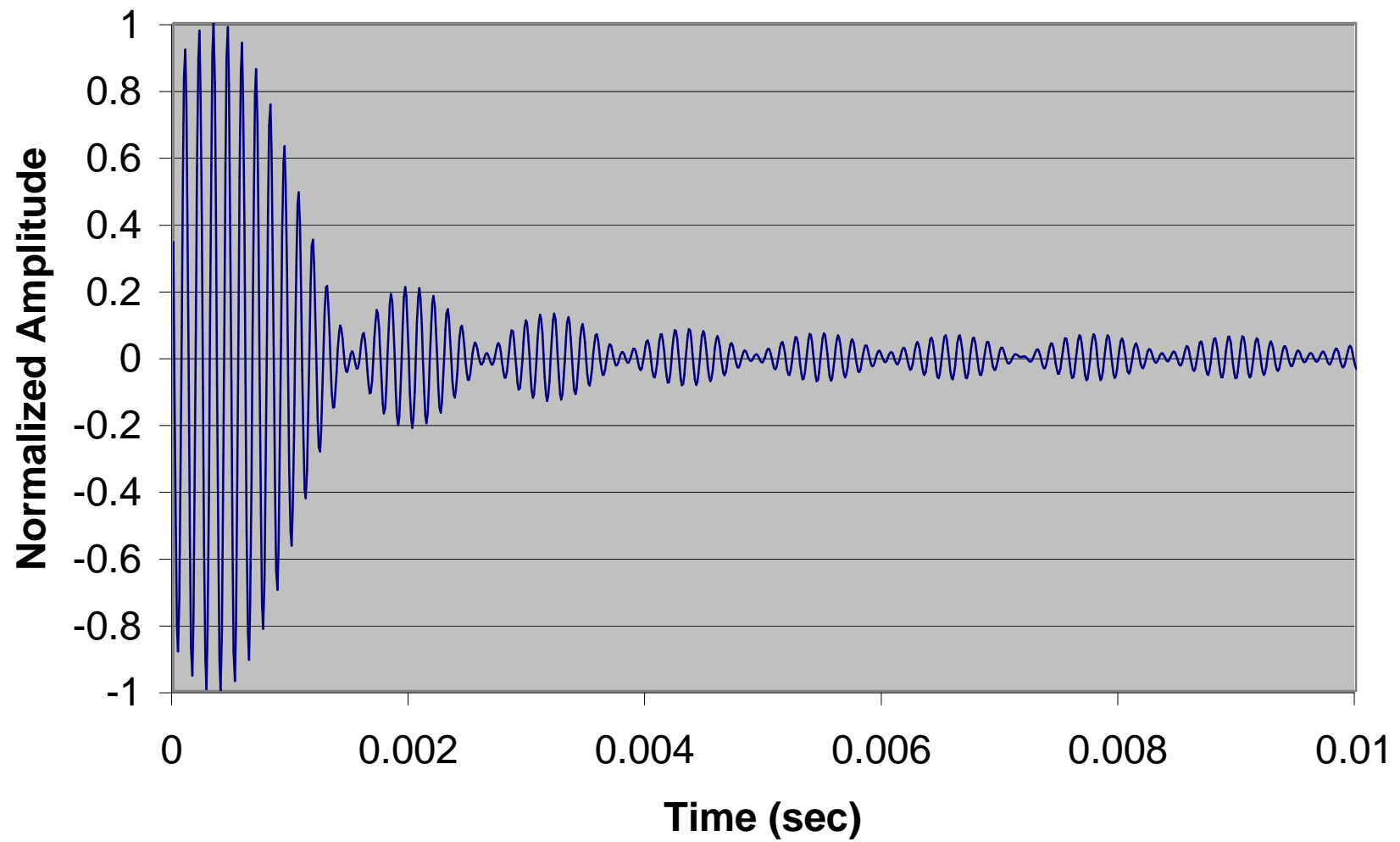
Tendon 3-3 Average - Filtered



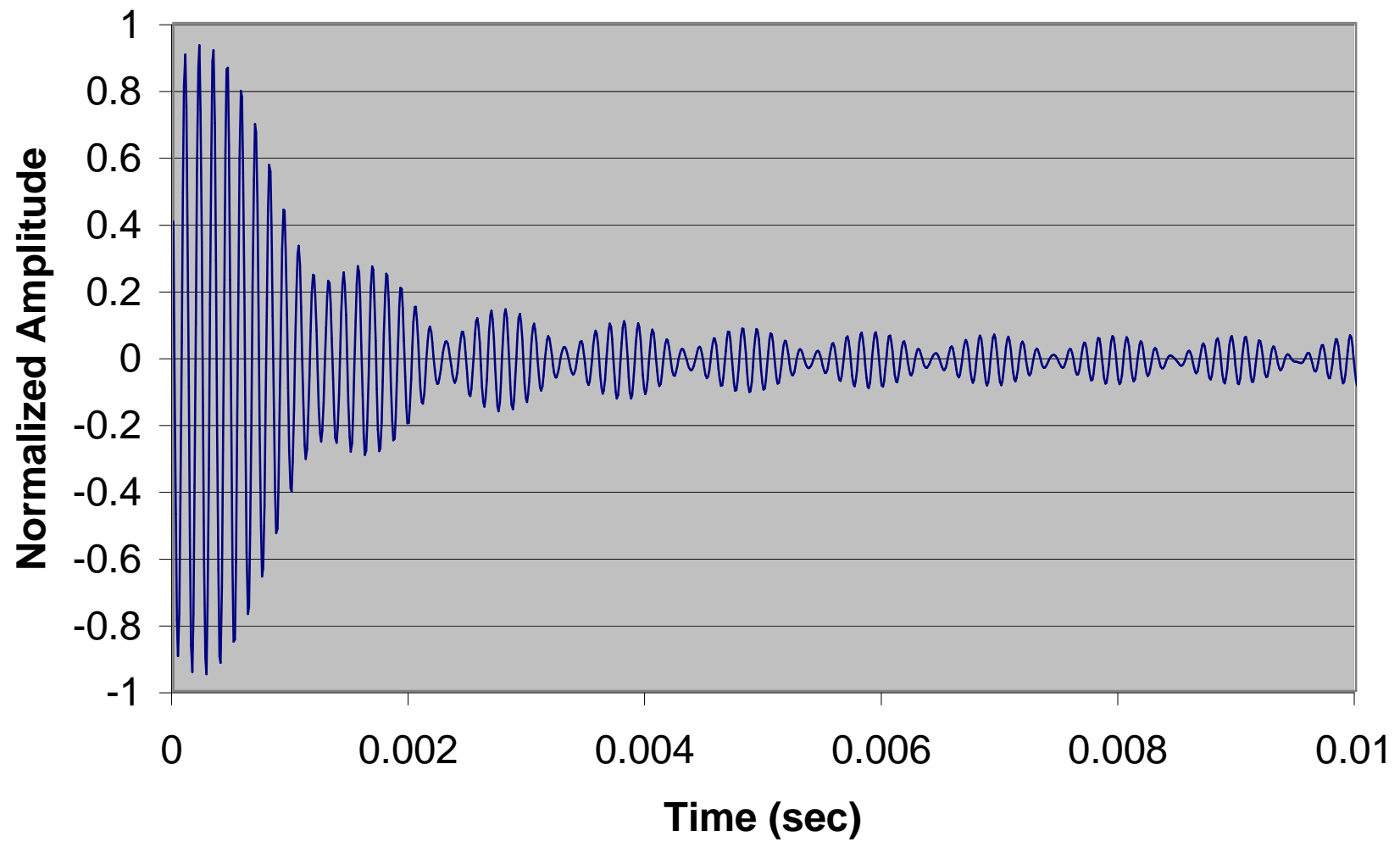
Tendon 3-4 Average - Filtered



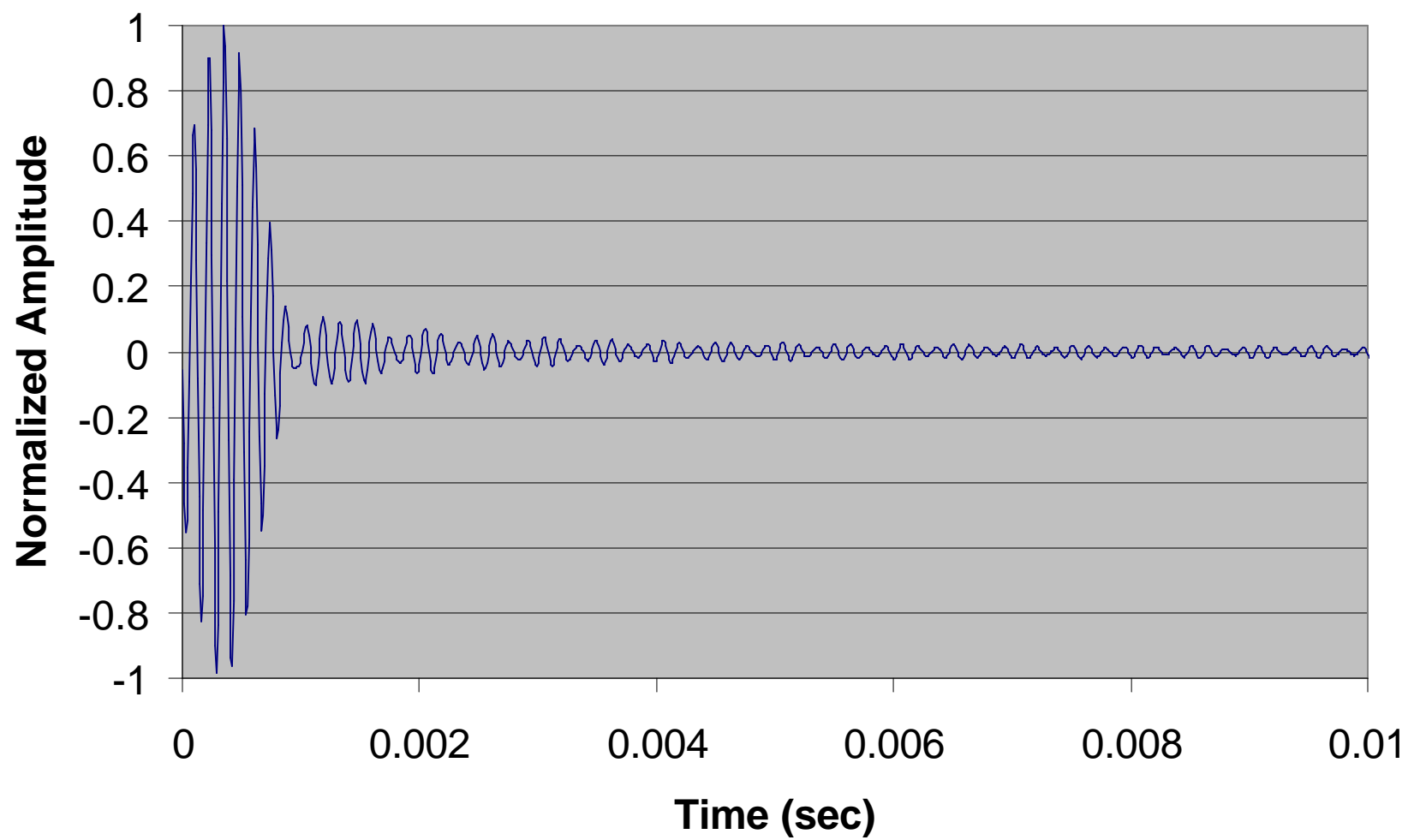
Tendon 4-1 Average - Filtered



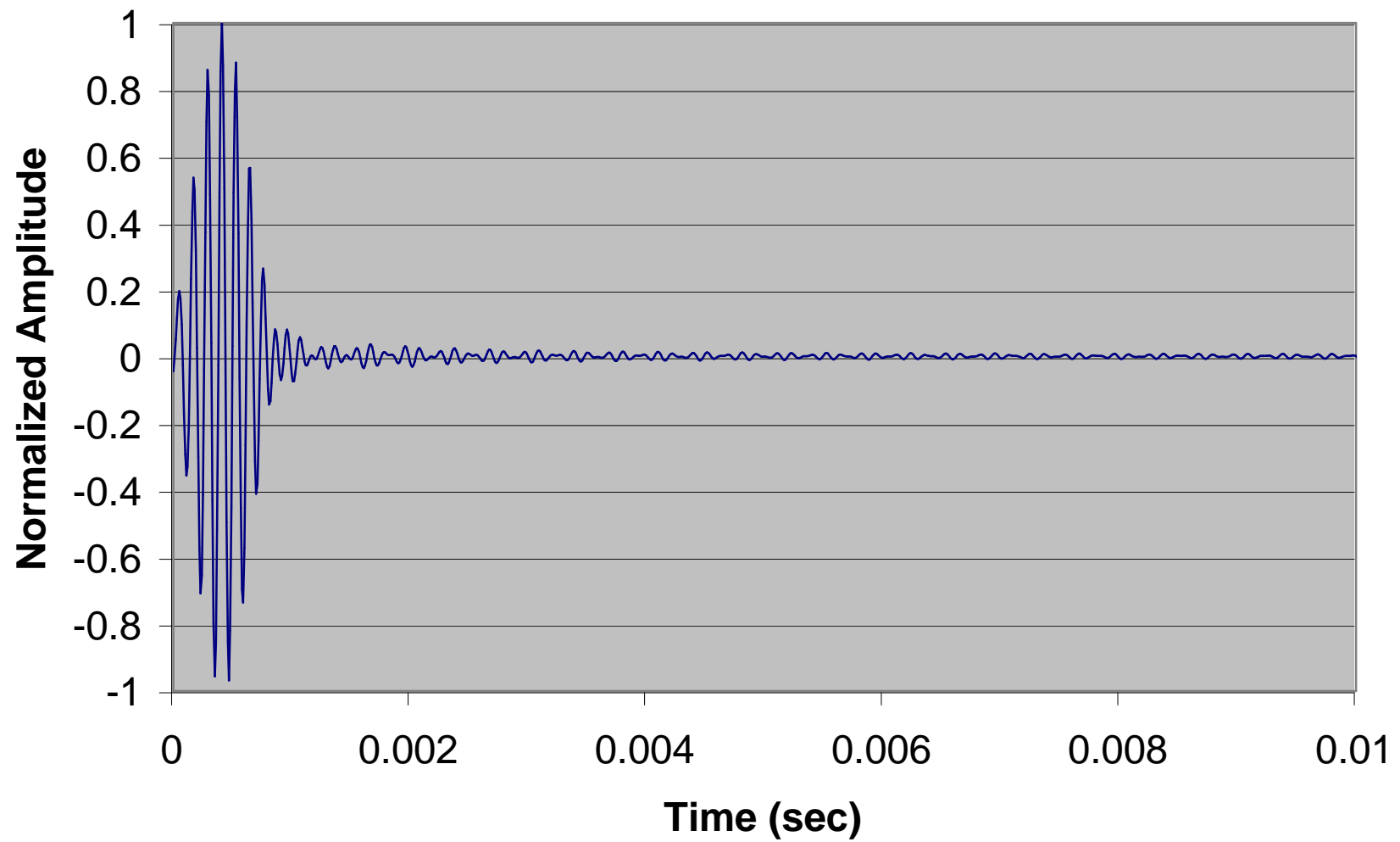
Tendon 4-2 Average - Filtered



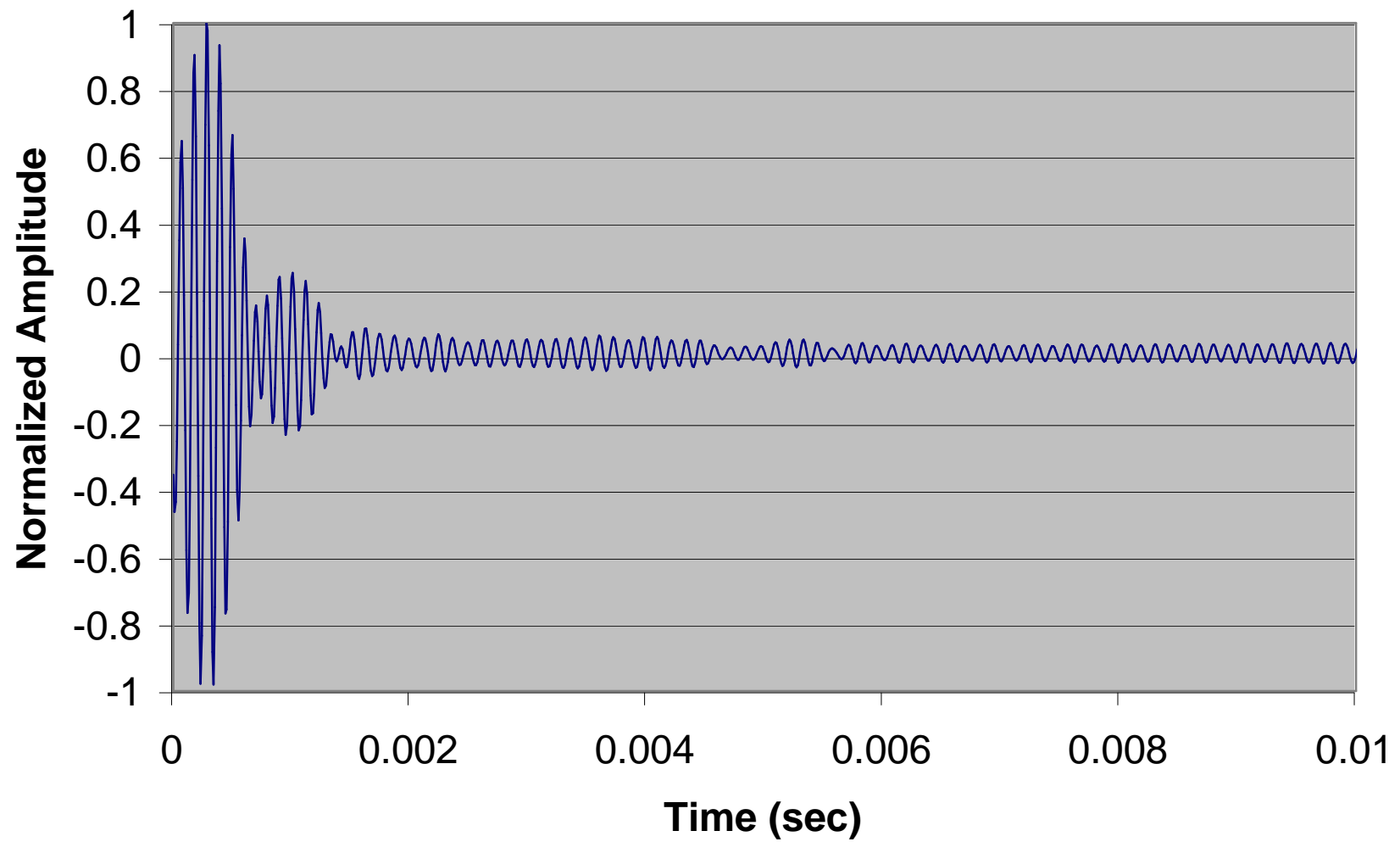
Tendon 4-3 Average - Filtered



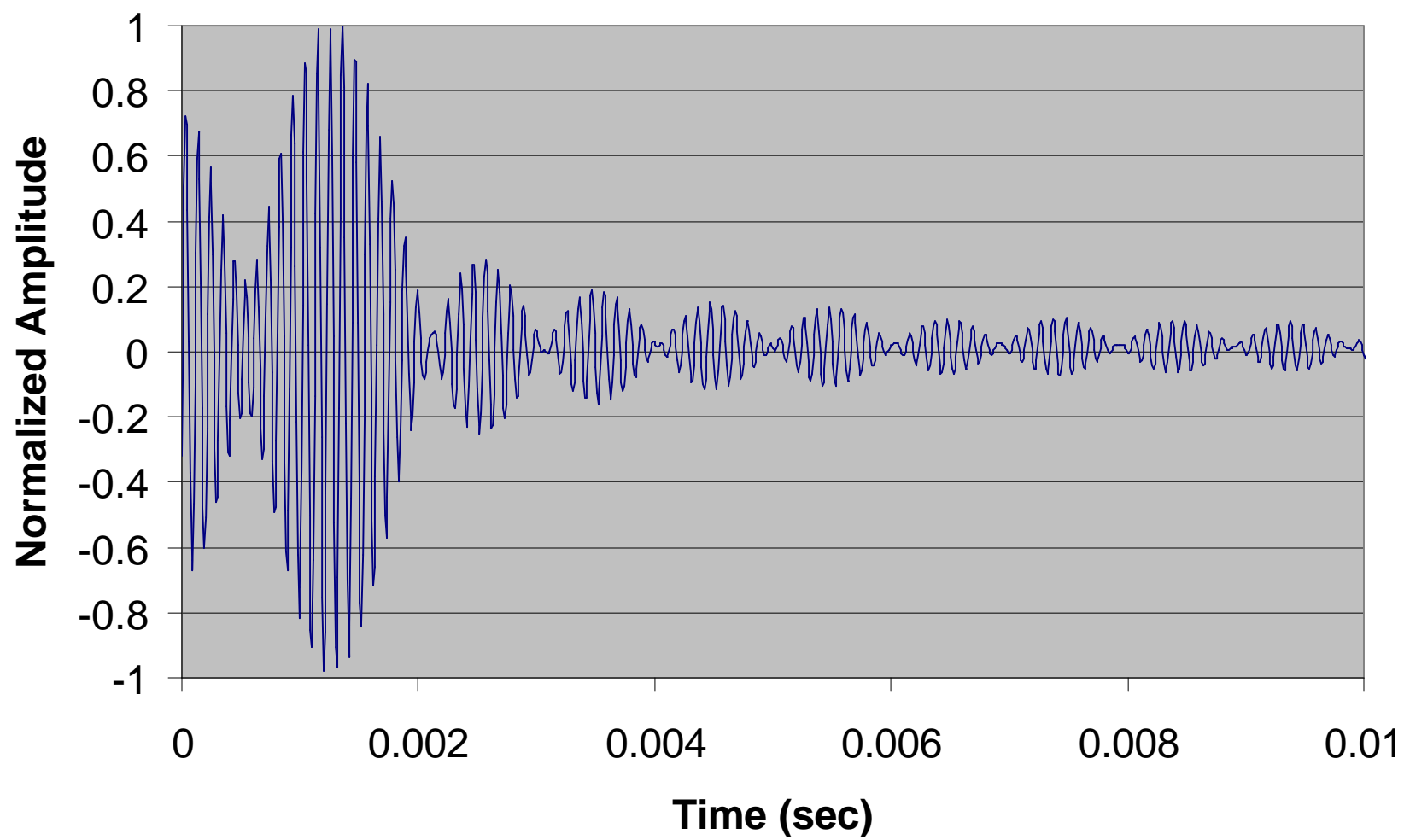
Tendon 4-4 Average - Filtered



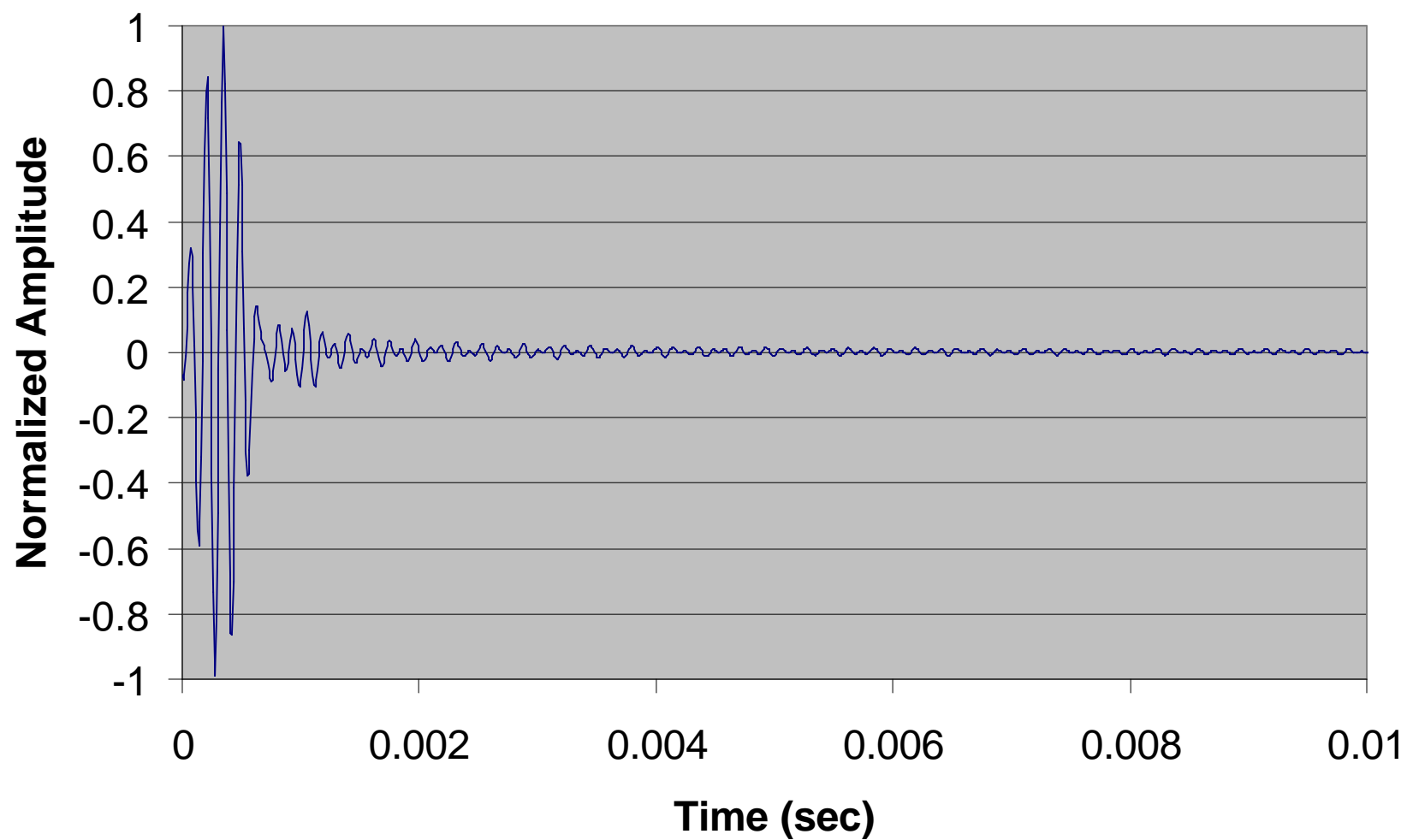
Tendon 5-1 Average - Filtered



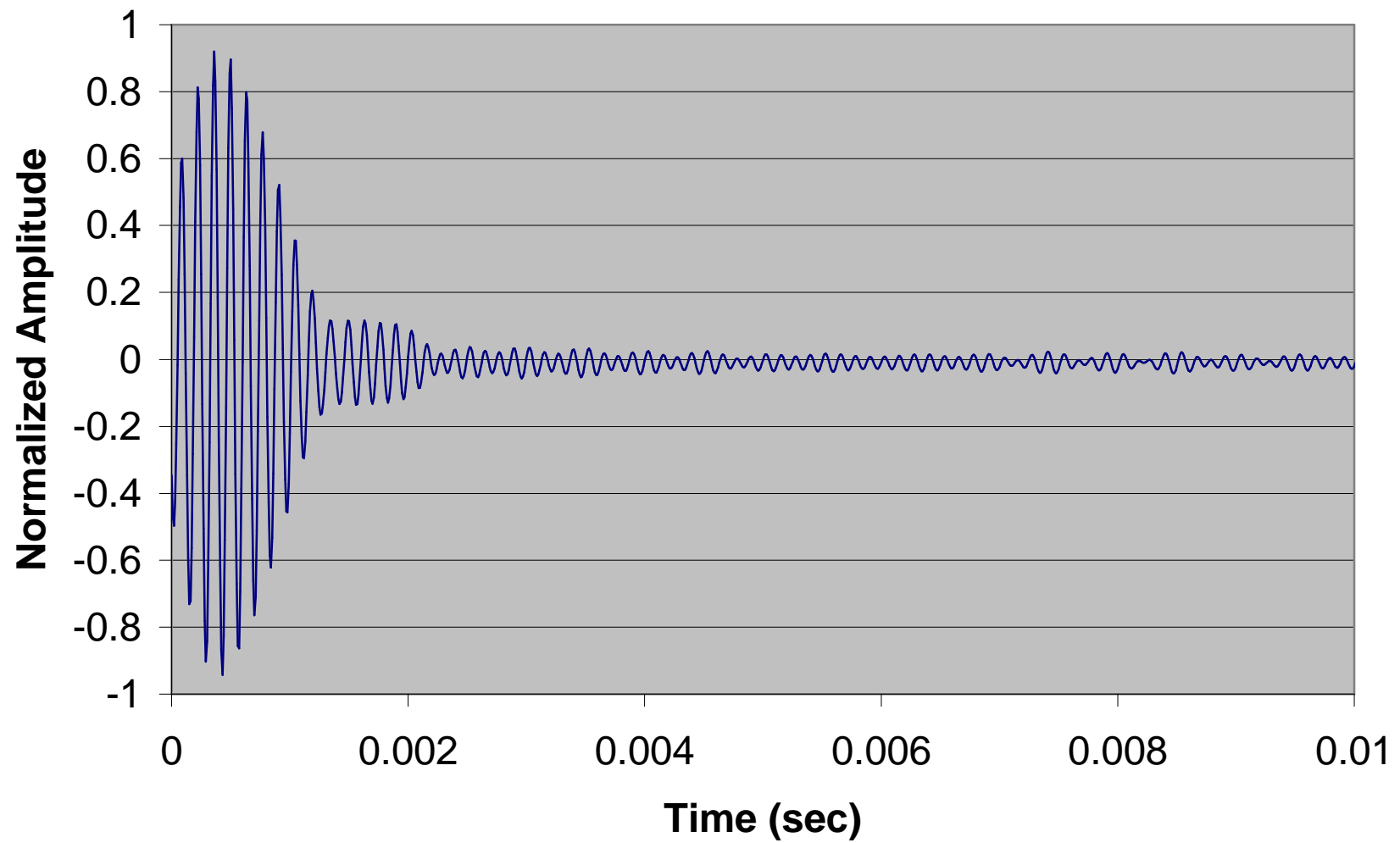
Tendon 5-2 Average - Filtered



Tendon 5-3 Average - Filtered



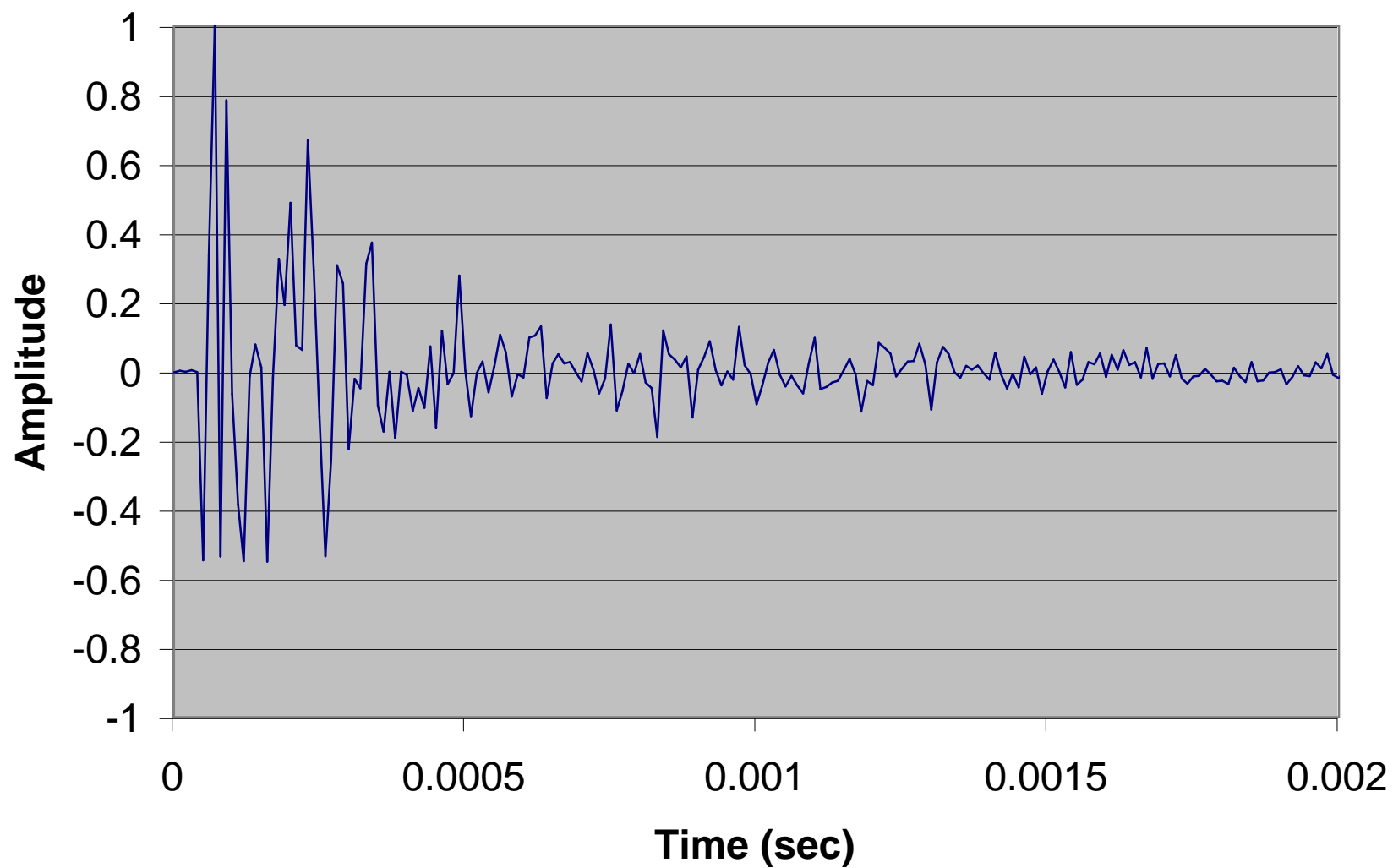
Tendon 5-4 Average - Filtered



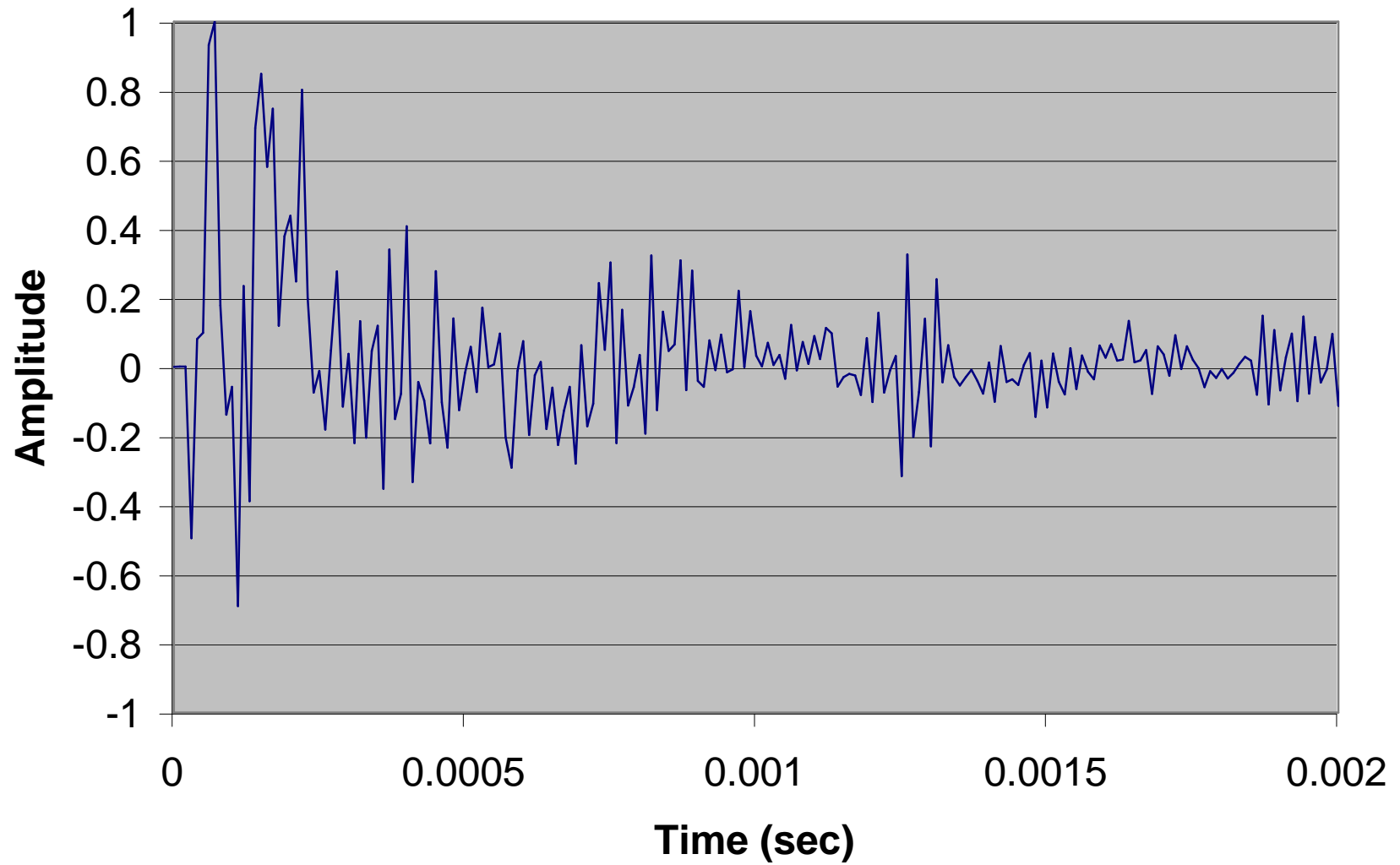
APPENDIX IX

ROCK BOLTS
ULTRASONIC TEST DATA

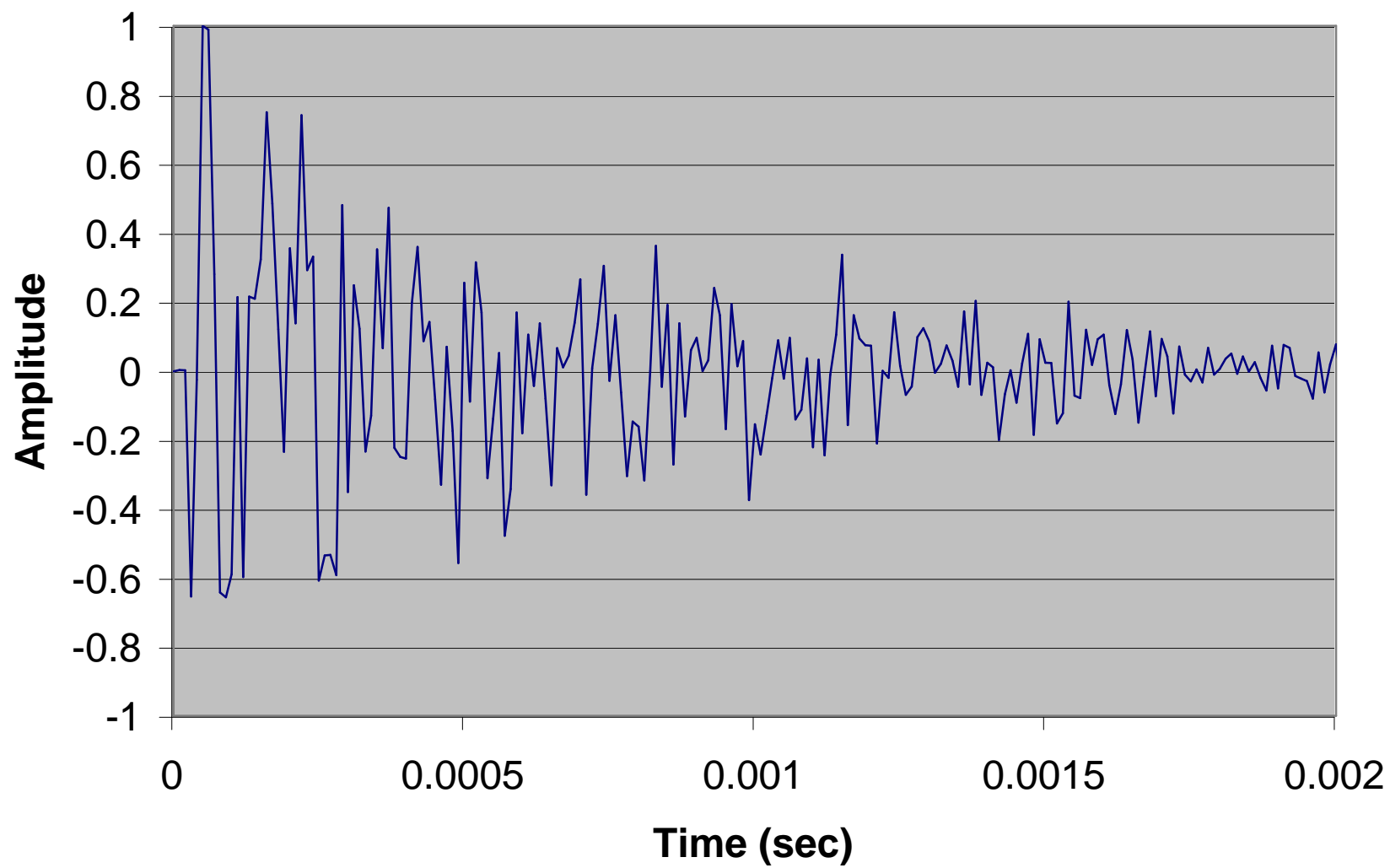
Ultrasonic Test - Bolt 1a (normalized)



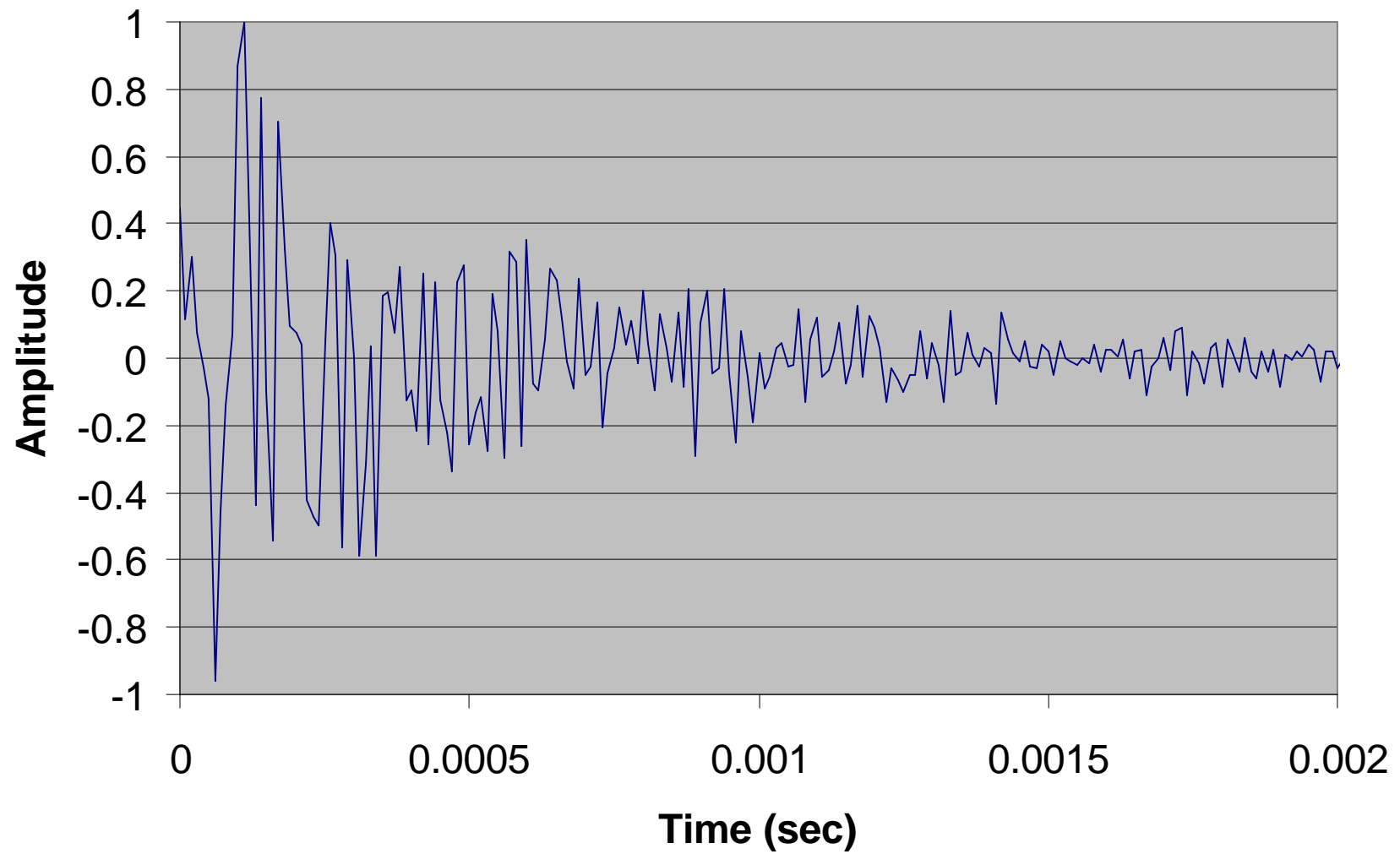
Ultrasonic Test - Bolt 2 (normalized)



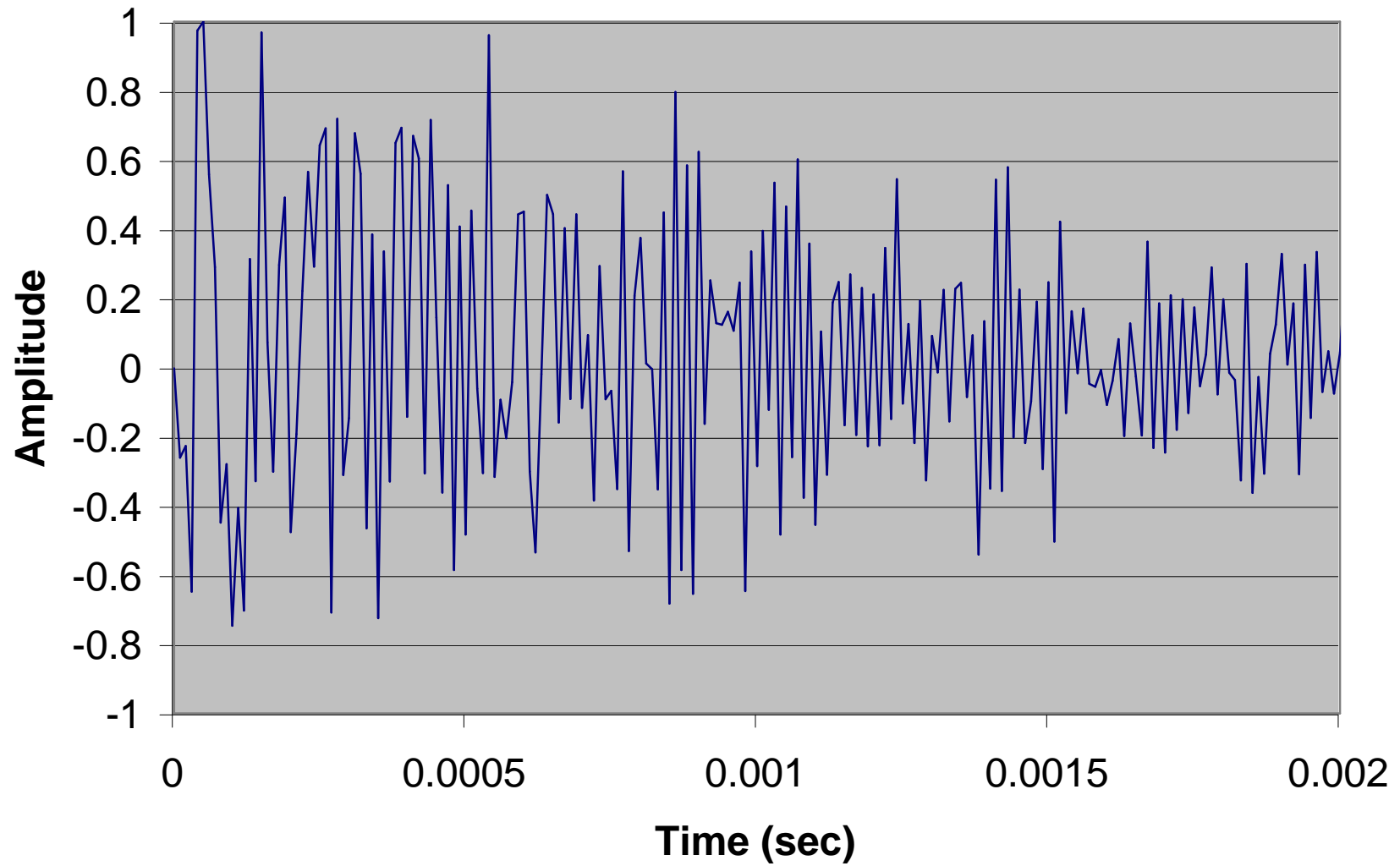
Ultrasonic Test - Bolt 4a (normalized)



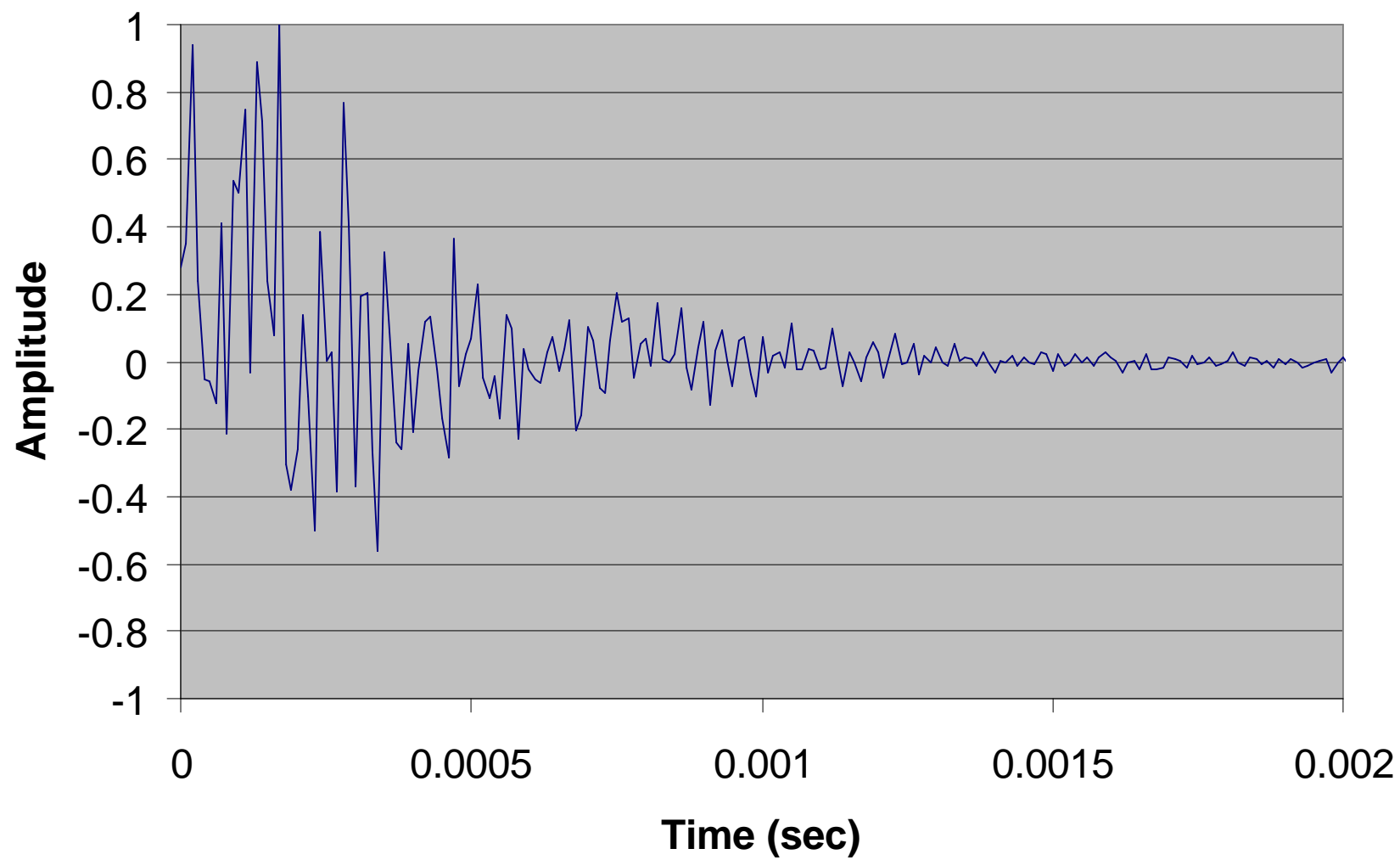
Ultrasonic Test - Bolt 5 (normalized)



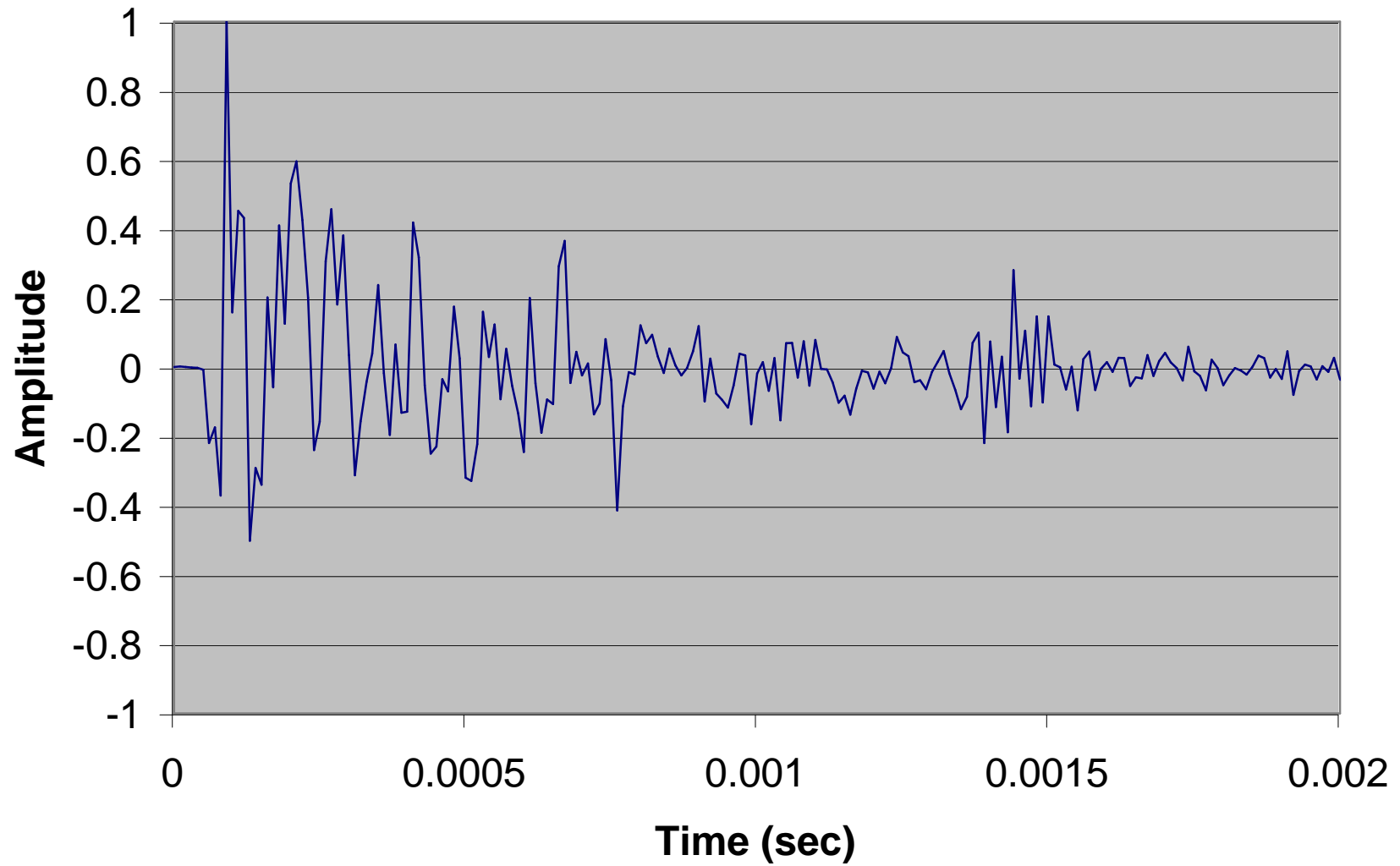
Ultrasonic Test - Bolt 6 (normalized)



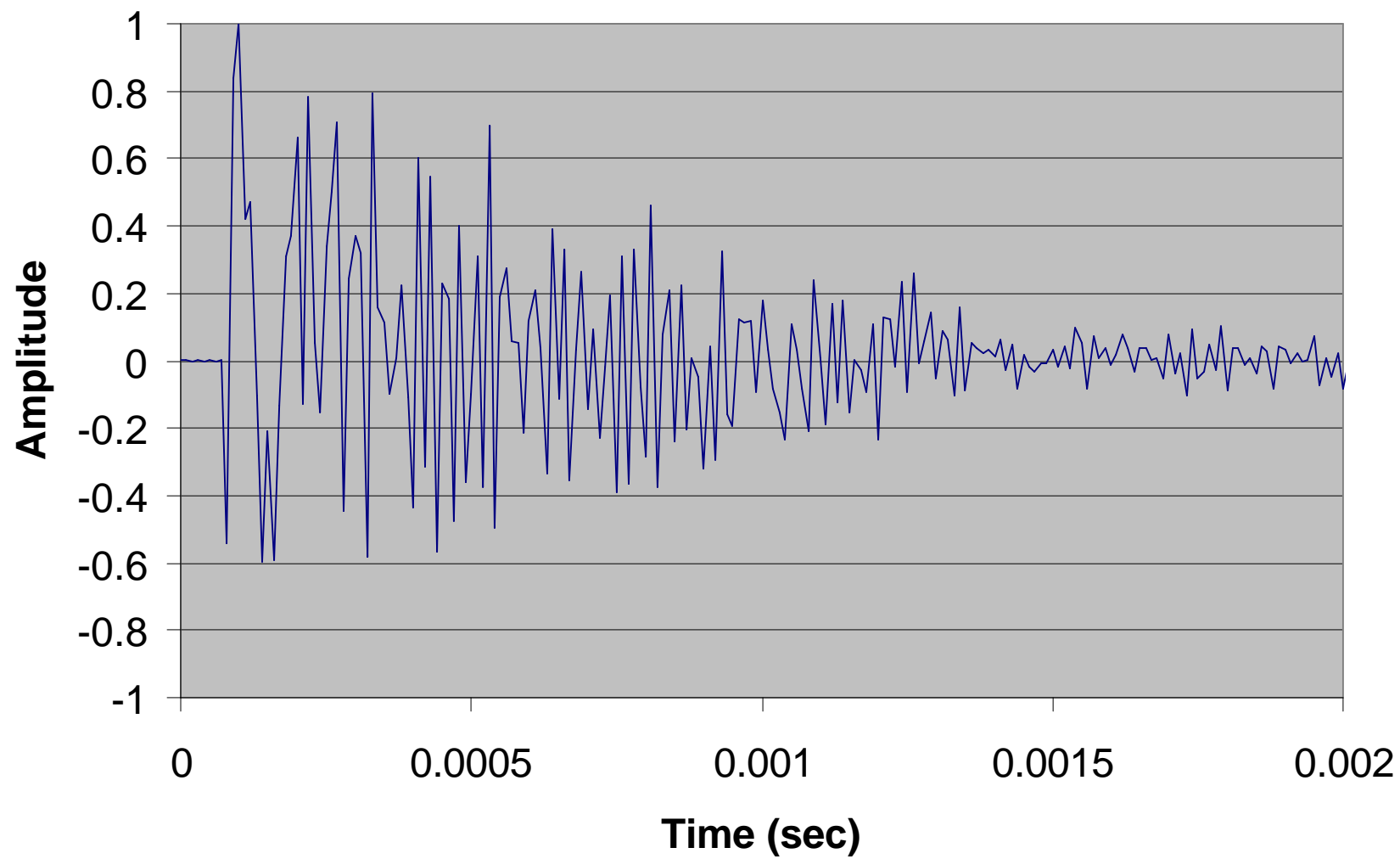
Ultrasonic Test - Bolt 7 (normalized)



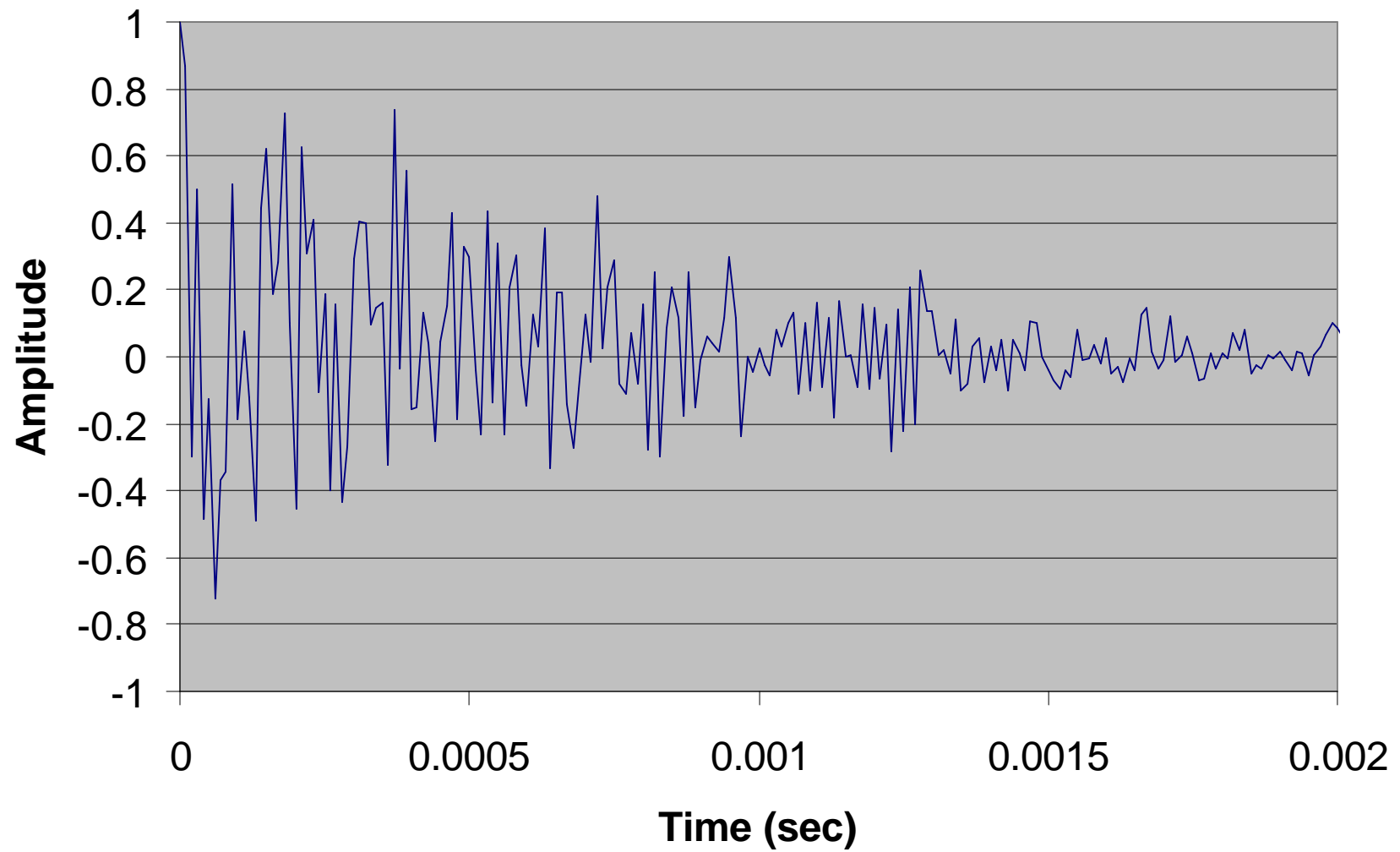
Ultrasonic Test - Bolt 8 (normalized)



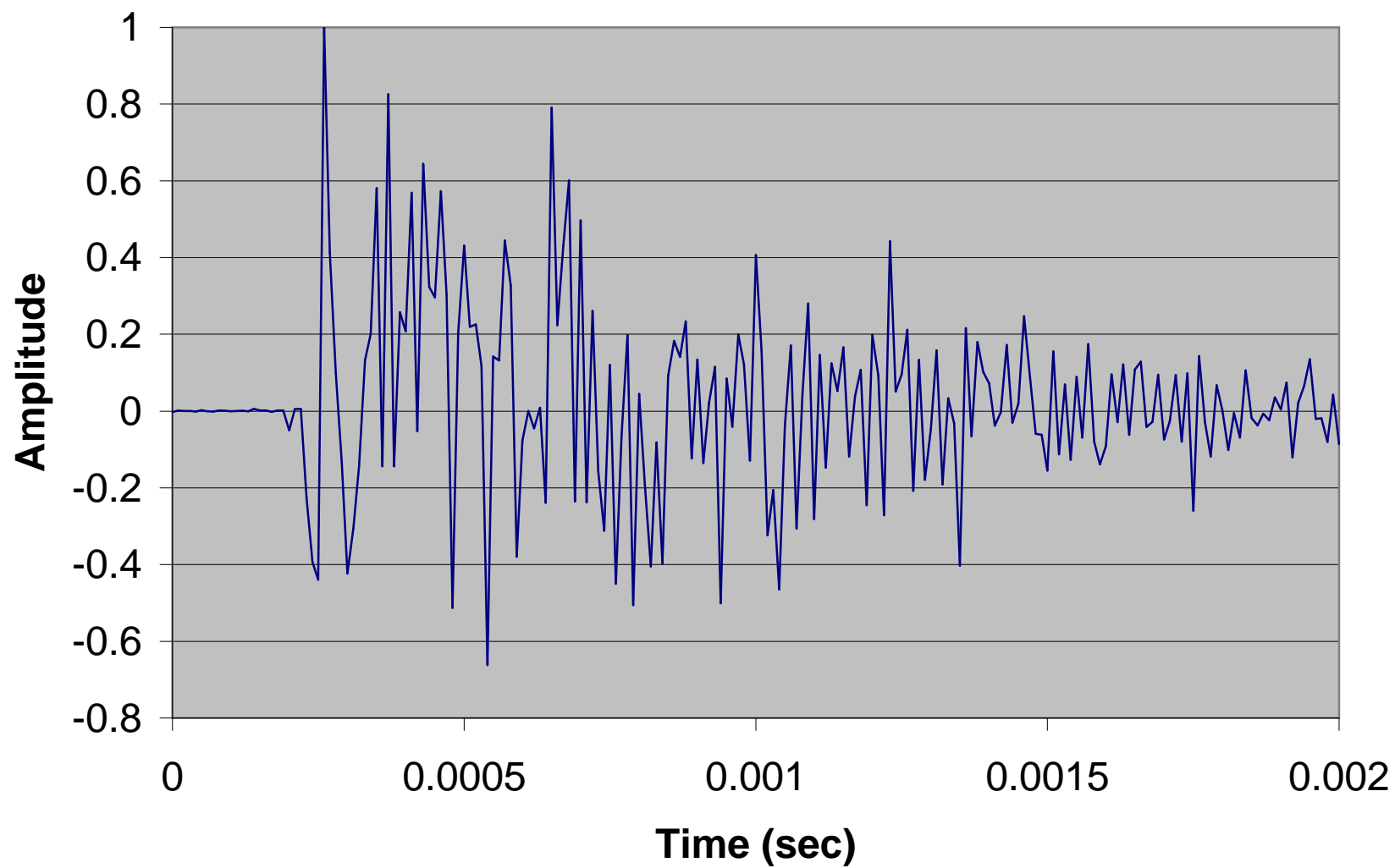
Ultrasonic Test - Bolt 9 (normalized)



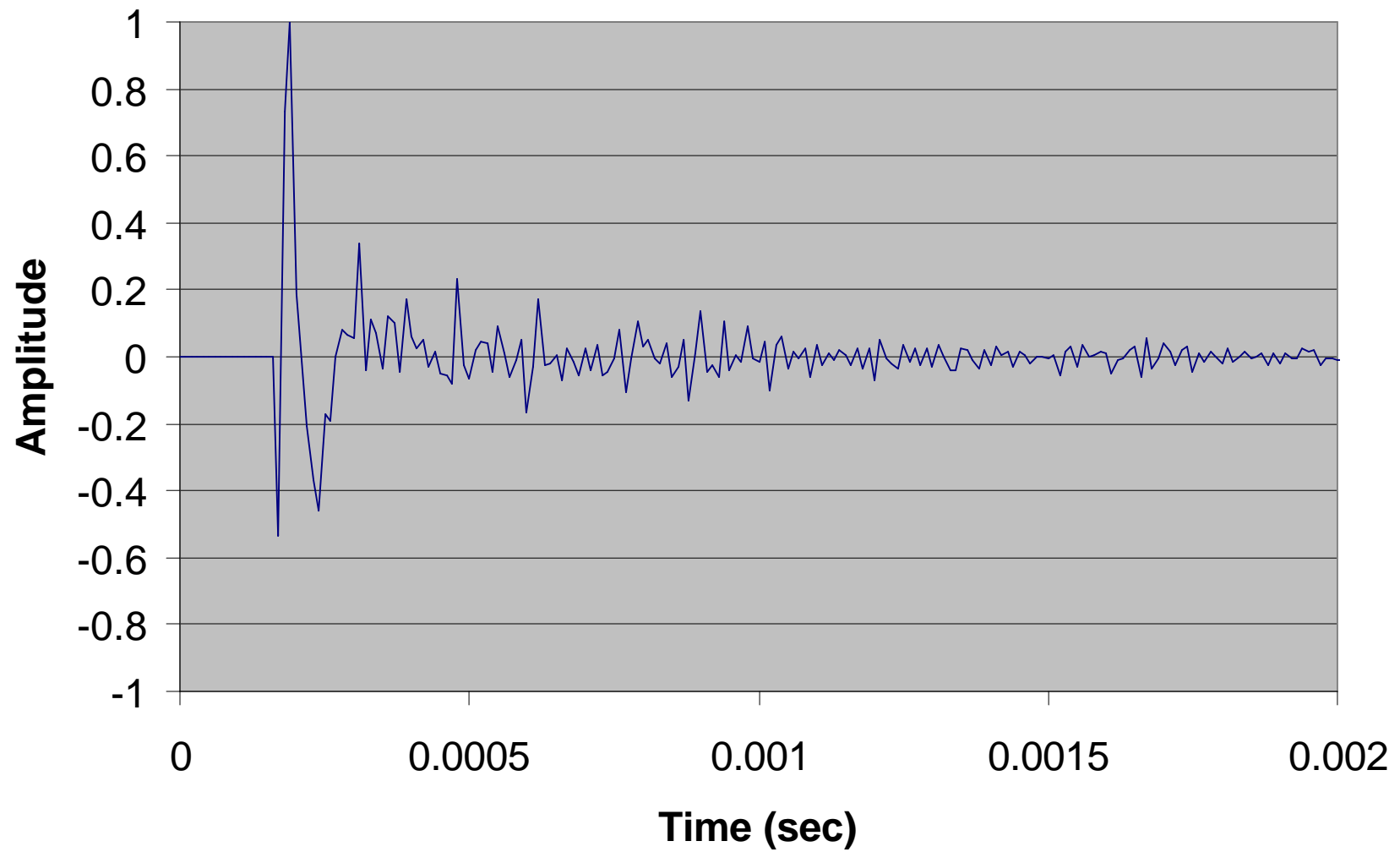
Ultrasonic Test - Bolt 10 (normalized)



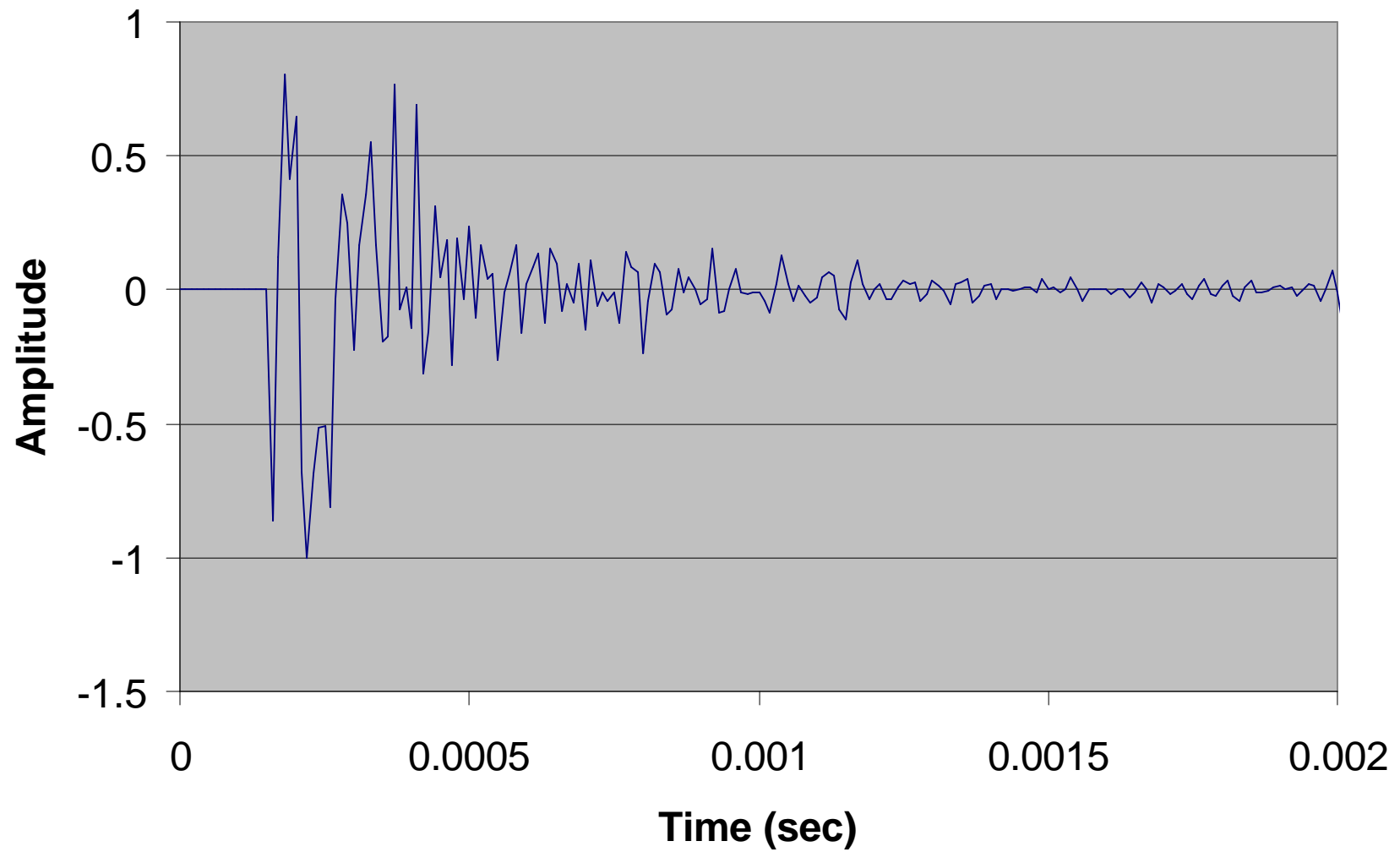
Ultrasonic Test - Bolt 11 (normalized)



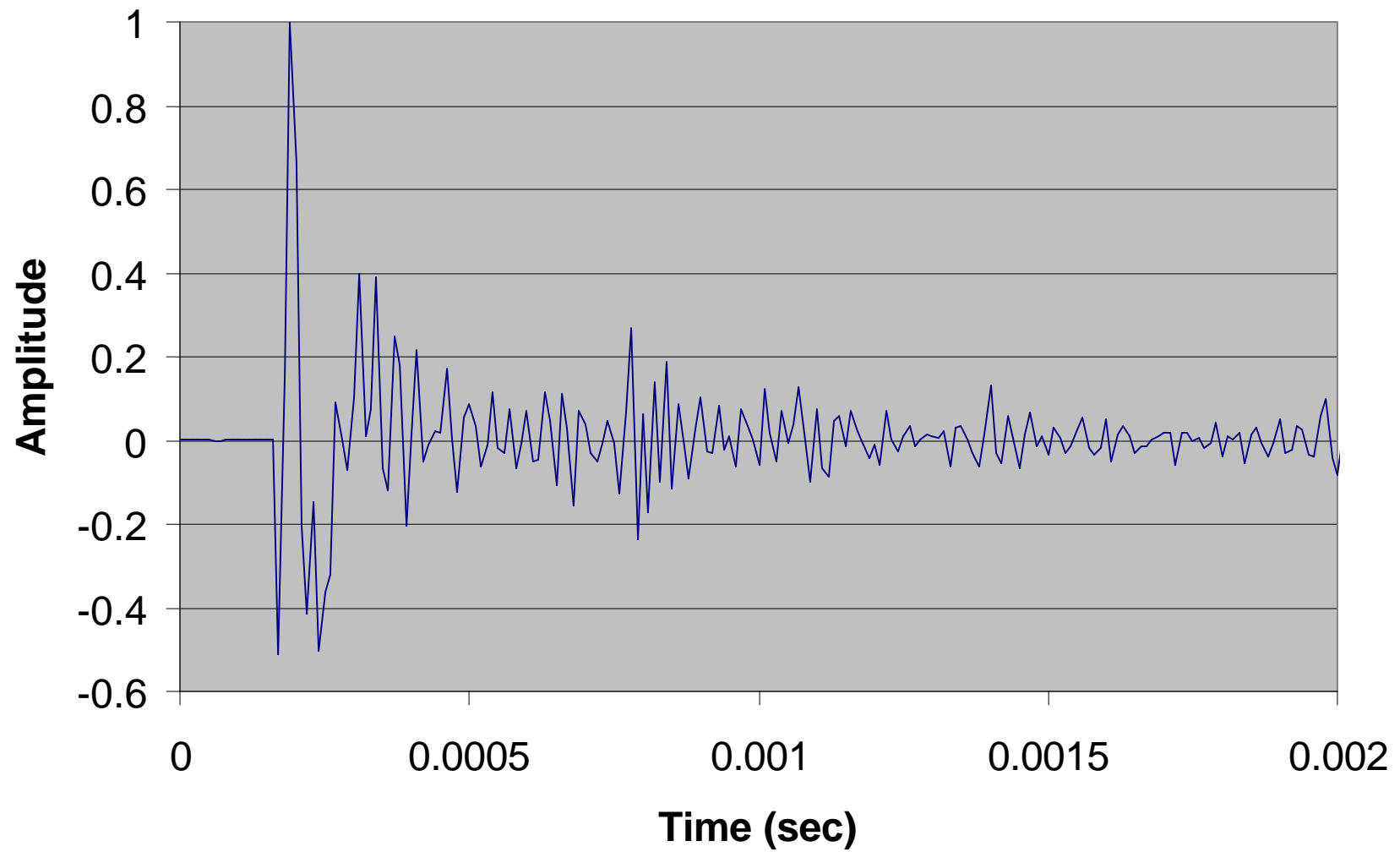
Ultrasonic Test - Bolt 12 (normalized)



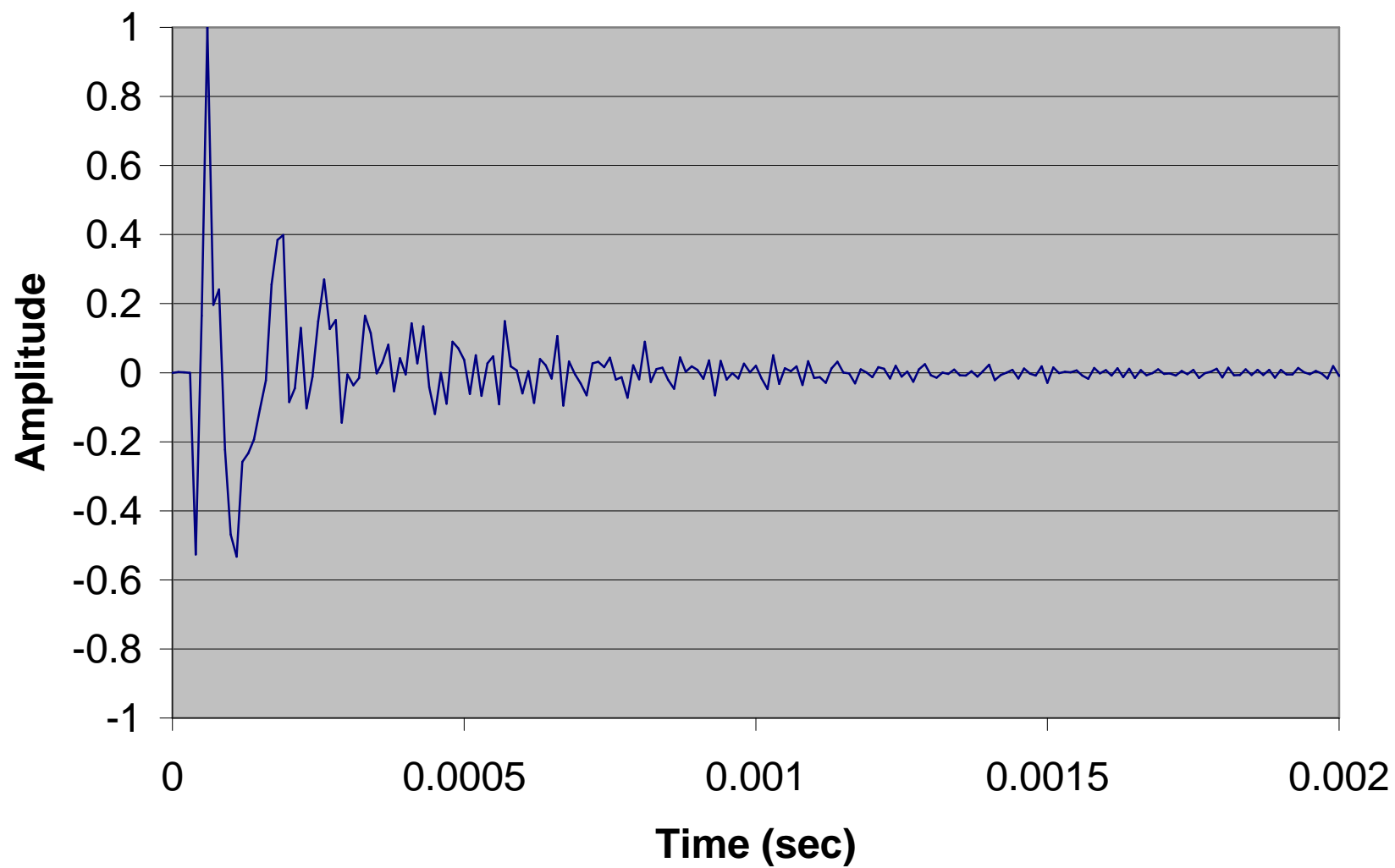
Ultrasonic Test - Bolt 13 (normalized)



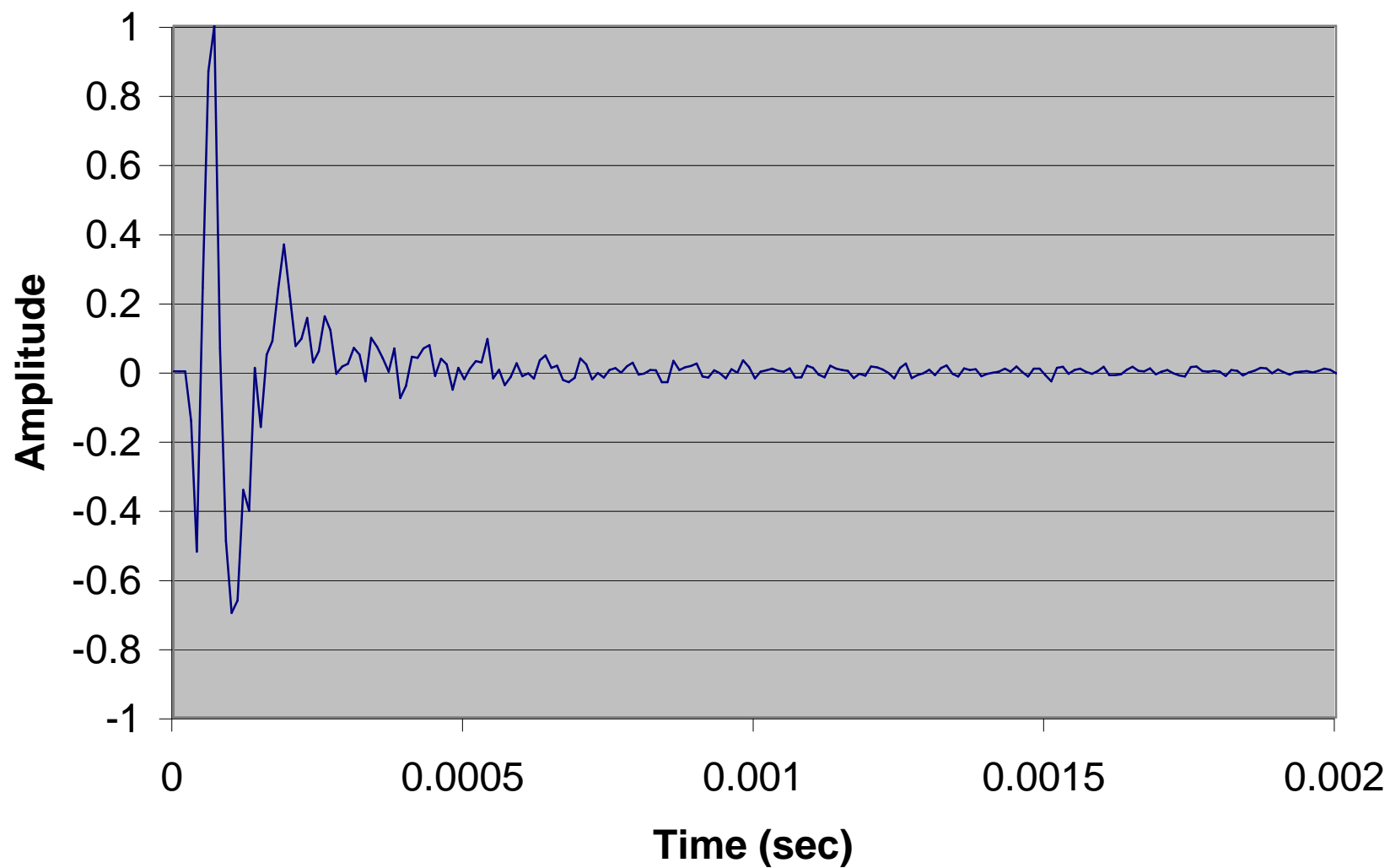
Ultrasonic Test - Bolt 14 (normalized)



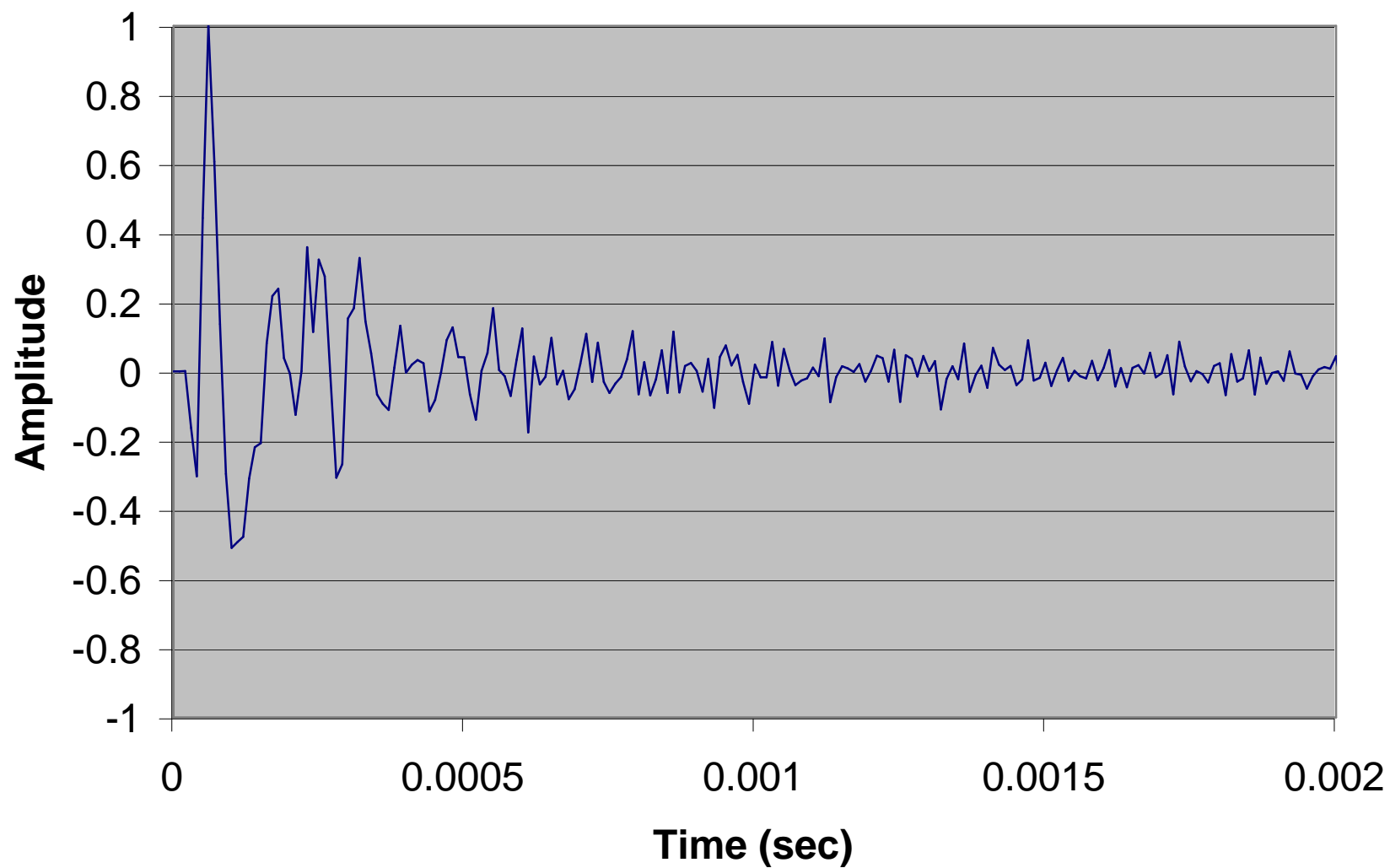
Ultrasonic Test - Bolt 15 (normalized)



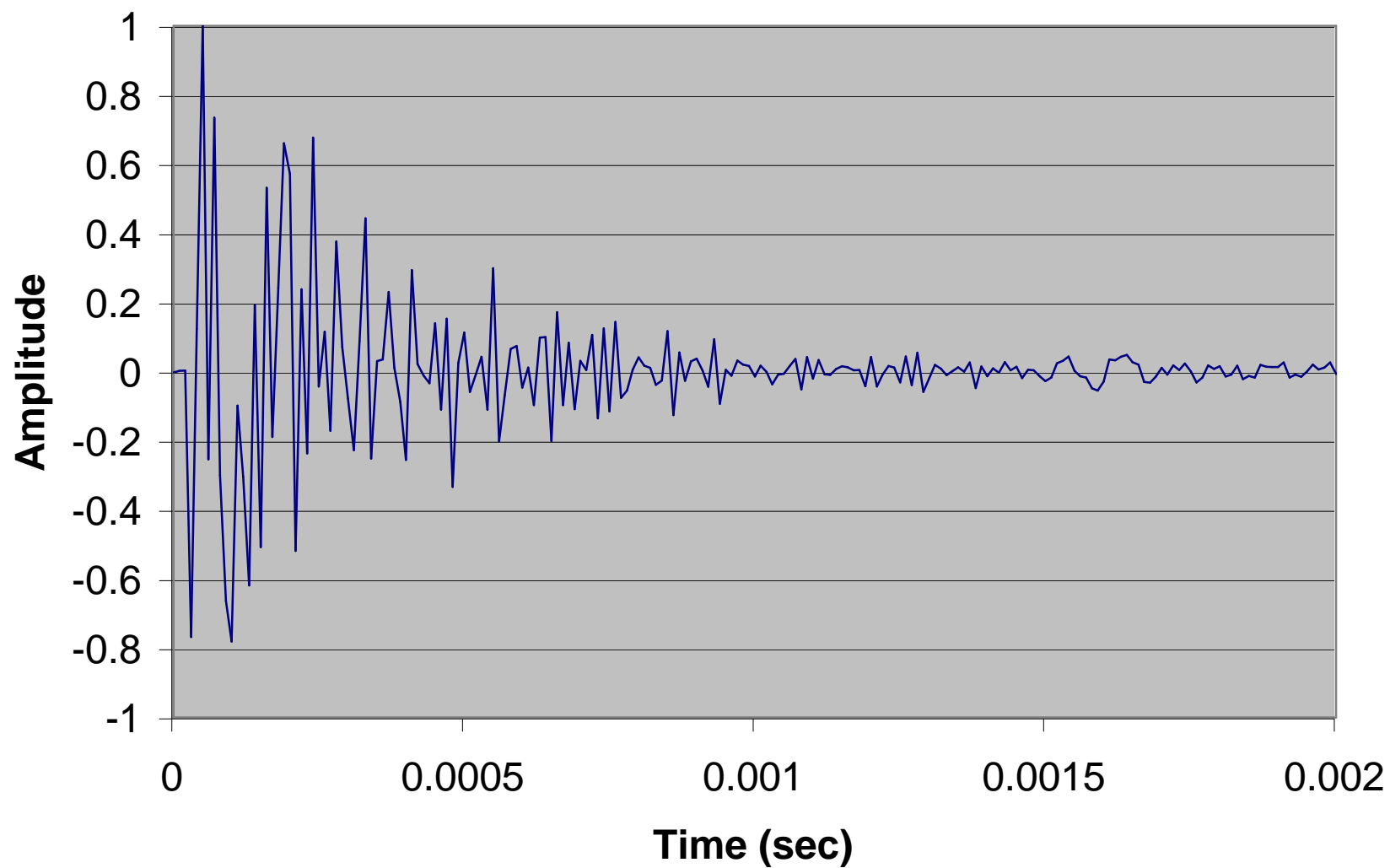
Ultrasonic Test - Bolt 16 (normalized)



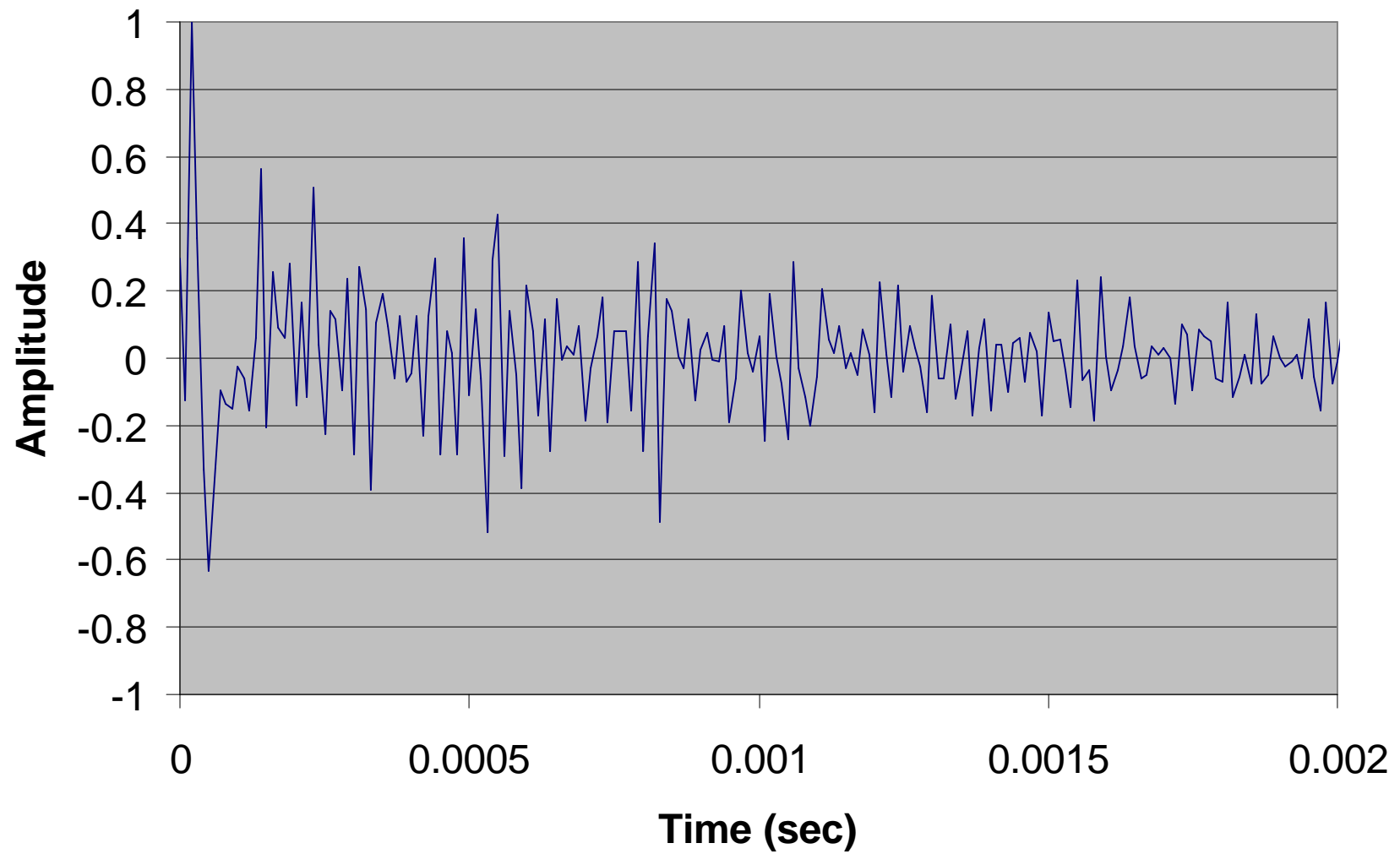
Ultrasonic Test - Bolt 17 (normalized)



Ultrasonic Test - Bolt 18 (normalized)



Ultrasonic Test - Bolt 19 (normalized)



Ultrasonic Test - Bolt 20 (normalized)

